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Developments in international solid biofuel trade—An analysis of volumes, policies, and market factors

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A B S T R A C T

This paper presents and analyses international solid biofuel trade and concludes upon interactions with bioenergy policies and market factors. It shows that trade has grown from about 56 to 300 PJ between 2000 and 2010. Wood pellets grew strongest, i.e. from 8.5 to 120 PJ. Other relevant streams by 2010 included wood waste (77 PJ), fuelwood (76 PJ), wood chips (17 PJ), residues (9 PJ), and roundwood (2.4 PJ). Intra-EU trade covered two thirds of global trade by 2010. Underlying markets are highly heterogeneous; generally though trade evolved whenever supply side market factors coincided with existing/emerging demand patterns. Market factors and policies both defined trade volumes; though policy changes did not have as prominent effects on trade developments as in the liquid biofuel sector. Economic viability is the key limiting factor. Main exporting countries have low feedstock costs and already existing wood processing industries. Trade-relevant aspects are the commodity's monetary value; determined by its homogeneity, heating value, and bulk density. Consumer markets are diverse: in residential heating, demand/trade patterns have been influenced by local biofuel availability and short-term price signals, i.e. mainly price competitiveness and investment support for boilers/stoves. Commodities are mainly sourced regionally, but price differences have triggered a growing trade. The industrial segment is greatly influenced by policy frameworks but more mature (e.g. established routes). Trade is strictly linked to margins (defined mainly by policies) and combustion technologies. Uncertainties in the analysis are due to data gaps across and within databases regarding import/export declarations. To estimate bioenergy related trade, anecdotal data was indispensable. We believe datasets should be streamlined across international institutions to eventually enable reporting of global trade beyond digit-6-level. Research is needed to provide further insights into informal markets. Interrelations between trade factors are particularly relevant when mapping future trade streams under different policy/trade regime scenarios.

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1. Introduction, problem definition, outline

Currently, biomass for energy purposes (bioenergy) contributes around 50 EJ (roughly 10%) to total global primary energy supply [1]. Yet, almost two thirds of the bioenergy is used locally in traditional cooking and heating applications in developing countries. The remaining part (around 38%) can be regarded as 'modern' usage, i.e. with higher conversion efficiency and for the production of high temperature heating, power, or road transportation [1–5].[1] Current policy frameworks, e.g. for GHG emission reduction or the diversification of energy supply, imply a trend towards an increased utilization of modern bioenergy. This includes a further replacement of traditional with modern bioenergy usage. An increasing use of modern bioenergy will inevitably be intertwined with large-scale international trading activities of bioenergy commodities. Contributing factors for this trend will be mainly economic reasons (influenced by policies) and biomass availability restrictions.

The dynamics of this interrelation are though not without risks for involved actors. As Lamers et al. [7] show for liquid biofuels, sudden changes in the underlying (trade) policy and market frameworks have contributed to several market disruptions and inefficiencies in the past. While solid biofuels are not yet traded to the extent as liquid biofuels, they are expected to become the next global commodity (see, e.g. [8]). Plus, the young market is similarly volatile, being influenced by various policies and external market factors. Yet there is little knowledge on how these aspects interrelate and shape its developments. Early lessons drawn upon past developments might help reduce uncertainties, prevent sudden (trade) policy changes and increase investment and planning security for private and public market actors. Providing insight in the total biomass market also makes clear where opportunities or conflicts may emerge with increasing demand for bioenergy.

Several valuable studies have presented analysis on market developments, trade volumes and interrelations for solid biofuels [9–25]. Nevertheless, they neither encompass a comprehensive collection and analysis of production and trade data over several consecutive years on a global scale, nor do they link policy and trade measures influencing (those) trade developments over time. In addition, they often cover one specific commodity whereas this study takes the dynamics between commodities into account.

The purpose of this paper is to identify and present global data on solid biofuel trade, to analyze the underlying trade patterns, and to conclude upon their interactions with bioenergy policies. The scope of the analysis is limited to direct trade of commodities for modern bioenergy use in markets where respective policies are in place. Trade flows not directly related to energy usage, e.g. internationally traded wood chips, of which a fraction ends up as black liquor in the pulp and paper industry and is used for energy (see, e.g. [14] for a distinction in the case of Finland) are not examined, as bioenergy is a by-product and not the main reason for trading. In the context of this article, such trade is referred to as 'associated'.[2] Trade in markets without respective policies (e.g. charcoal in Africa) was not investigated since an integral part of the analysis is the evaluation of policy impacts on the respective trade flow developments.

The methodology underlying the analysis is presented in the following section. Section 3 presents the 'big picture', i.e. an overview of global solid biomass production and trade to put energy related developments into perspective and to identify the relevant, policy influenced bioenergy markets. Section 4 zooms in on those markets and provides details of trade developments and (net) volumes. Linkages between the trade developments, policy and market factors are established in Section 5. The paper closes with reflections and conclusions. Background information on policies, production and trade data, and conversion factors are presented in Appendixes 1–3.

2. Methodology

The analysis was limited to commodities that potentially may (also) be used and traded for bioenergy; e.g. because of their

[1] The consumption of traditional bioenergy is still increasing in most developing countries; its share in total energy consumption however is declining due to faster growth in the use of fossil fuels [6].

[2] This term is used to avoid similarities with the term 'indirect' as, e.g. in indirect land-use change where it refers to macro-economic, distributional effects. Nevertheless, 'indirect' appears to be commonly used in the relation to solid biofuels (e.g. bark trade) by other authors.

Table 1
Overview of selected trade codes.

	CN/HS2	Chapter description	CN/HS4	CN/HS6	Code definition
Agricultural residues	12	Oilseeds and oleaginous fruits, miscellaneous grains, seeds and fruit, industrial or medicinal plants, straw and fodder	1213	121300	Cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets
	18	Cocoa and cocoa preparations	1802	180200	Cocoa shells, husks, skins and other cocoa waste
Industrial residues	23	Residues and waste from the food industries, prepared animal fodder	2302	230200	Bran, sharps and other residues, whether or not in the form of pellets, derived from the sifting, milling or other working of cereals or of leguminous plants
			2303	230310	Residues of starch manufacture and similar residues
				230320	Beet-pulp, bagasse and other waste of sugar manufacture
			2306	230660	Oilcake and other solid residues, whether or not ground or in the form of pellets, resulting from the extraction of palm nuts or kernels
Forestry	44	Wood and articles of wood; wood charcoal	4401	440110	Fuel wood (logs, billets, twigs, faggots or similar forms)
				440121	Wood in chips or particles (coniferous)
				440122	Wood in chips or particles (non-coniferous)
				440130	Sawdust and wood waste and scrap, whether or not agglomerated in logs, briquettes, pellets or similar forms
			4402	440200	Wood charcoal (including shell or nut charcoal), whether or not agglomerated
			4403	440320	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared coniferous
				440391	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared oak
				440392	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared beech
				440399	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared of other (poplar, eucalyptus, birch)

HS: harmonized system, i.e. international coding of the World Trade/Customs Organization.
CN: combined nomenclature, i.e. trade coding of the EU (first 6 digits are similar to HS).

relatively high calorific value, favorable combustion characteristics, and/or relatively low economic value. International trade data was derived for a choice of commodities from the agricultural, industrial, and forestry sector (see Table 1). Based on this, commodities were selected that show either a non-constant development over the past decade, i.e. obviously reacting to recently introduced bioenergy policies, are directly linked to energy usage (e.g. fuelwood), or generally encompass (very) large trade quantities (see Fig. 1).

To dimension global biomass production and trade volumes, an upper limit was derived via databases of internationally recognized institutions (see Section 3). The main benefit of this approach is the availability of data for various commodity streams over several consecutive years. In addition, streams within databases are clearly

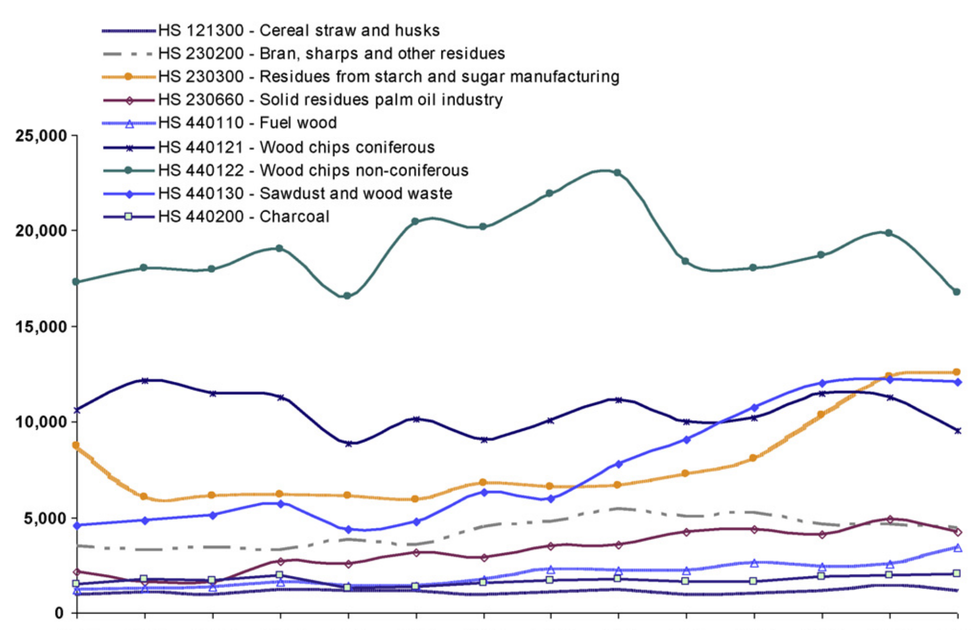

Fig. 1. Global solid biomass trade streams (>900 ktonnes) in ktonnes based on imports based on [27].

distinguishable from each other; yet definitions and categories may vary across databases. The respective international records often build upon national statistics, i.e. figures were deemed to be reliable and have undergone prior scrutiny.

Production data for forestry products (other than pellets and waste wood) was taken from FAOSTAT [26]. COMTRADE [27] and EUROSTAT [28] served as the primary basis for trade data on global and EU level respectively since they allow differentiations by trade code. Since trade in FAOSTAT [26] is not categorized via codes, only code-similar data sets could serve as benchmarks against UN [27] statistics. Furthermore, international trade codes are only harmonized until digit-6-level which allows for differences between COMTRADE [27] and EUROSTAT [28] as the latter is available up to digit-8-level. For example, sawdust (agglomerated in pellets, briquettes, or else) and waste wood are grouped under the same code (*HS 440130*). Code on digit-8-level is required to distinguish between these trade flows. While this is possible on EU-level (*CN 44013020* for pellets, *CN 44013080* for wood waste and scrap), international trade data [27] is not available in such detail. Wherever possible, data on the highest code level was chosen for the analysis.

Generally, (partially large) differences were encountered when comparing trade flow declarations on their import and export side within and across databases. For the upper limit the respective maximum values (in any given year) were taken. International trade codes (up to digit-8-level) do not allow differentiating by end-use. Hence, reported volumes include energy related and other streams, e.g. for material purposes in the case of wood chips. International data can therefore generally be considered as a (often largely theoretical) upper limit of possible biofuel trade volumes. To obtain solely bioenergy related production and trade streams (see Section 4), it was indispensable to rely on anecdotal evidence via conference presentations, speeches, and/or interviews of internationally recognized experts in the field from academia, consulting, and private market parties. Their insights were also used to define net solid biofuel trade. The respective assumptions for the calculations are presented in Section 4.6. The approach takes multi-counting risks into account.

Production and trade are primarily influenced by economic drivers. Since bioenergy-specific support and other policies influence economics, coupling volumes to polices and market factors is done via an inventory and analysis of past or existing policies aimed at stimulating the solid biofuel market, i.e. production, trade, and/or consumption in the focus region. A cross-check with interviewees was done to guarantee the significance of the respective policy frameworks. Trade balances of the focus regions were taken as indicators whether the policies primarily stimulated local production and/or trade. Interviewees were also asked to list and explain the factors which they believe have triggered initial trade volumes. In the case that several factors were mentioned, volume developments over time were taken as indicators to define the importance of either one.

3. Global solid biomass production and trade

Fig. 1 shows the relative importance, i.e. varying volumetric dimensions of the commodities as selected in Table 1.

3.1. Industrial roundwood

Data by FAOSTAT [26] shows that industrial roundwood trade grew from 66 Mtonnes in 1996 to 108 Mtonnes in 2007, after which it dropped to 76 Mtonnes in 2009.[3] This makes it the largest absolute trade stream in focus; especially when considering that industrial roundwood trade data excludes bark, i.e. actual volumes are about 10–12% higher [15,29]. However, relative to production (see Fig. 2), only 7–8%[4] of globally produced industrial roundwood has been traded internationally. This indicates that industrial roundwood has been primarily used locally. It also implicates that the core producing centers are home to the world's major wood processing industries. Global roundwood production between 2000 and 2009 has been dominated to over 50% by only five countries (see Appendix 1 for quantitative details): USA (24%), Canada (11%), Russia (8%), Brazil (7%), and China (6%) [26]. World exports have been primarily covered by Russia (33%), followed by the USA (9%), New Zealand (6%), Germany (5%), and Malaysia (4%). The top importers have been China (23%), Finland (10%), Japan (9%), Sweden and Austria (each 7%) [26].[5]

The recent decline in trade and production can largely be attributed to the economic downturn in 2008/2009 and the introduction of export duties on roundwood in Russia. After the collapse of the Soviet Union, the Russian forest industry had to cope with stagnating investments and a drop in internal market demand for raw and processed wood. As a consequence, Russia became the world's top exporter of unprocessed roundwood [15,30]. To reduce export volumes and to increase local wood processing, export tariffs on roundwood were raised in 2007 [30,31]. However, Russian exports in processed wood never reached desired levels due to a lack of investment in processing infrastructure and a global decline in wood products demand – both partly fuelled by the global financial crisis [32]. As a result, export tariffs were not raised further after 2009. Interestingly, while overall Russian wood exports (*HS 44*) declined, fuelwood exports doubled between 2007 and 2009 [32]. In 2008 and 2009, Russia also exported an additional 456 ktonnes of wood chips; 97% of which were exported to Finland [27]. Wood chips in Finland though are exclusively used in pulp and paper production [33].

The majority of global roundwood production and trade is not directly linked to energy policy developments. However, there is a large amount of associated trade in the form of bark and residues from wood processing [14,33]. In recent years, declines in sawmill output have caused roundwood to be used as input material in pellet production. This is also partly related to trends in paper production, i.e. a shift in production from the Northern to the Southern hemisphere; leaving Scandinavia, North America, and Russia with considerable surpluses and causing whole stems to be used for bioenergy (see Section 4.2). In the future, expected regional shortages of industrial roundwood supply, the expansion of biorefinery concepts, and liquid biofuel production from lignocellulose might also affect energy-related roundwood trade [34–36].

3.2. Fuelwood

Fuelwood (*HS 440110*) accounts for roughly two thirds of global bioenergy use (around 33.5 EJ), primarily in the form of traditional heating and cooking [1,6]. Global fuelwood production has grown from 497 Mtonnes in 2000 to 509 Mtonnes in 2009 (see Fig. 2) [26]. Two thirds of all countries have increased their production by a total of 45 Mtonnes; the remaining third dropped theirs by a combined 33 Mtonnes [26]. Major increases have taken place in India, Ethiopia, and Congo; the largest reduction has been observed in China, Indonesia, and Russia. In total, the largest fuelwood producers have been India (17%), China (10%), Brazil (8%), Congo (4%),

[3] According to COMTRADE [27], combined trade volumes for HS 4403 commodities selected in Table 1 have been between 75 and 874 ktonnes annually over the same period.

[4] If not indicated otherwise, relative values for trade/production volumes are given as an average for the period 2000–2009/2010.

[5] See [15] for a geographical overview of industrial roundwood trade.

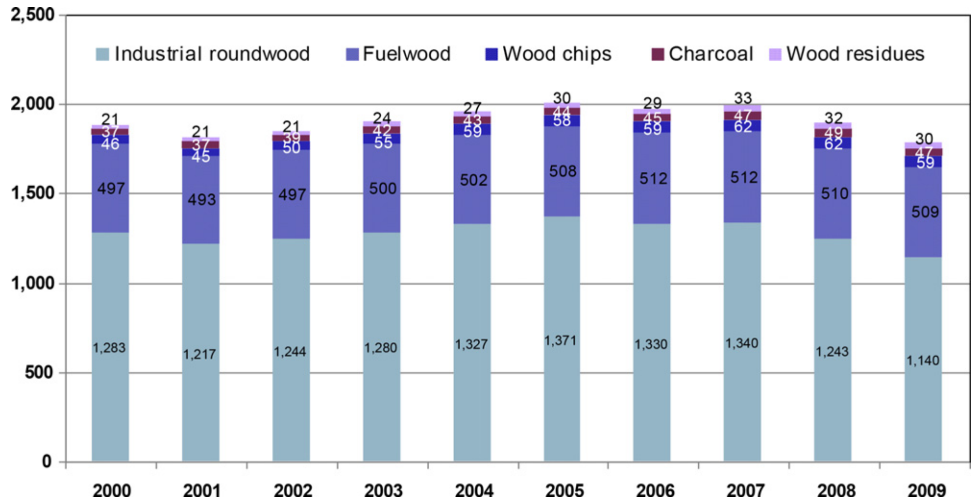

Fig. 2. World production of selected solid biomass types in Mtonnes based on [26].

Nigeria, and Indonesia (each 3%); their international trade volumes however have been negligible (see Table 5 in Appendix 2) [26,27].

Fuelwood is a rather local product; less than 1% of its production is traded annually according to official statistics. These though often exclude informal cross-border trade (which is difficult to monitor or estimate). According to COMTRADE [27], world trade has grown from 1.9 to 4.4 Mtonnes between 2000 and 2009. The EU27 has been the key driver and importer, covering over 50% of global trade between 2000 and 2004 and more than 80% between 2005 and 2009 (see Section 4.1) [27]. Over the whole period, the EU has also increased its production by 2.7 Mtonnes [26]. While France, Greece, Italy, and Estonia reduced their production; Germany, Poland, Austria, and Spain heavily increased theirs [26]. Fuelwood has practically no flow-ability and requires special handling in bulk transport. Most trade takes place cross-border, i.e. short- or mid-range in bagged form, conglomerated in nets, or stacked on pallets. Outside Europe, large (though mostly not policy stimulated) trade streams have taken place between South Africa and its neighboring countries (foremost Swaziland and Namibia), between Canada and the US, and across South East Asia [27].

3.3. Wood chips

With 18–23%, wood chips are by far the most traded commodity relative to their total global production volume (based on [26]).[6] They vary in quality (and application) depending on their source material. Wood chips for energy purposes are mainly derived from harvesting/forest or processing residues (branches, tree tops, thinnings, bark, etc.), other inferior wood not suitable for material or pulp and paper production, and recovered wood. Therefore, bioenergy related trade can fall either under the trade code for wood chips, i.e. *HS 440120* or (sawdust and) waste wood, i.e. *HS 440130* (see Section 3.4).

The vast majority of global trade as under code *HS 440120* (as shown in Fig. 1) refers to high quality chips for pulp and paper production. Wood chip and pulp and paper production and trade volumes have correlated, i.e. steadily grown until 2008 and declined afterwards as a result of the global financial crisis (see, e.g. [26,37] for pulp and paper production data). The main producers of wood chips across the past decade have been Canada (37%), Australia (8%), Sweden (7%), Russia (6%), and China/Finland (each 5%) [26] (see Appendix 1 for details). All countries also rank among the top pulp and paper producers.

Global wood chip trade has been partly cross-border (e.g. Finland-Russia, Canada-US) but also heavily driven by Japan (increasingly also China). Across the past decade, Japan has been attracting on average 35%, but in some years over 50% of all globally traded wood chips [27]. The shares of the second largest importers (Canada, Sweden, China, Finland) were below 5% of global trade on average across 2000–2009 [27].

According to Goto et al. [38], 3% of the total Japanese wood chip supply (of which more than 70% is imports) ends up in combustion plants. It is assumed though that the largest share of these chips is derived from domestic demolition wood which contributes 6–7% of the total wood chip supply in Japan [38]. Therefore, Japanese wood chip import trade streams are regarded to be exclusively pulp chips.

The EU has been a net importer of wood chips, sourcing (i.e. extra-EU) largely from Russia, Uruguay, Brazil, Canada, Congo, Belarus, and the Ukraine [28]. Extra-EU trade streams have primarily been directed to Austria and Italy [27]. Sweden and Finland, two other major importers source largely from within the EU or their border countries [28]. Top EU-exporters have been Germany, Latvia, and Estonia [28]. Cross-border trade with third countries has been especially active towards Switzerland (AU, DE, IT, FR), Norway (SE), Russia (FI, Baltic States), and Croatia (SI) [28]. The majority of European wood chip trade is covered by high quality pulp chips. Bioenergy related trade though is believed to rank second (see Section 4.2) [20,39,40].

3.4. Sawdust (pellets) and waste wood

Trade category *HS 440130 Sawdust and wood waste and scrap* covers a variety of woody residues which need to be distinguished for the analysis. Apart from combustion, sawdust (whether or not agglomerated in pellets) can be used in agriculture (foremost animal bedding) and industry (foremost as absorbent). The relative market share of the latter two application forms though has become marginal given the global trends in production and trade of wood pellets for energy purposes (see Section 4.5). Global pellet production grew almost tenfold from 1.6 to over 15 Mtonnes in ten years (see Fig. 3). Currently, the single largest producers are the USA, Canada, Germany, Sweden, and Russia (see Table 11 in Appendix 2). The industry has grown from small scale production units with capacities below 50 ktonnes and relying on surplus sawmill residues to (very) large scale plants whose individual capacities reach almost 1 Mtonne and encompass chippers to allow flexibility

[6] The relative trade varies significantly with the underlying data; based on COMTRADE [27] for *HS 440120* it is in the range of 44–68%.

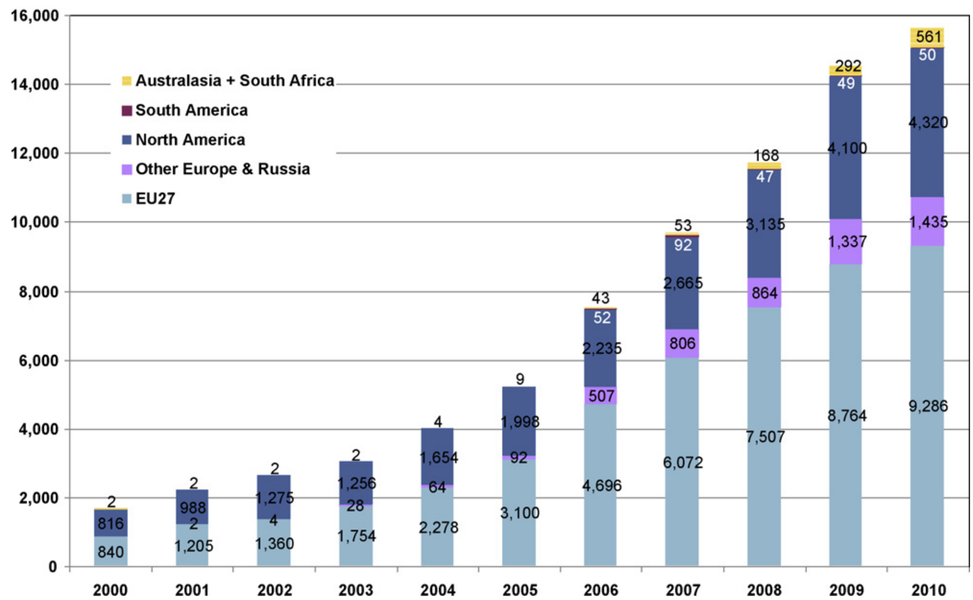

Fig. 3. Estimated world wood pellet production 2000–2010 in ktonnes based on [11,21,23,28,38,41–54].

in feedstock choice. Over the past decade, the leading consumer and importer of wood pellets has been the EU27; combusting more than two thirds of global production annually.

For 'waste wood', there is no standard definition, i.e. trade data might include a variety of streams from harvesting and processing residues, inferior (small diameter/low quality) roundwood to recycling/recovered wood (see [55] for a detailed discussion on EU level). Since recovered wood can theoretically be treated, e.g. with preservatives/coatings, it has to be handled, i.e. traded and disposed of (landfilled or combusted) in accordance with waste/environmental legislation. Recovered wood can theoretically also include hazardous materials (e.g. found in railway sleepers or utility poles). Since hazardous (e.g. construction) waste is often excluded from combustion, it is considered not to be traded for energy purposes, i.e. respective data is excluded from this analysis. Trade volumes in focus cover non-hazardous, used wood such as boxes, packaging cases, plywood, chip-, medium-density fibre-, or hardboards, and pallets.

No large scale intercontinental shipments of recovered wood for energy purposes are known to date. Wood waste appears to have been landfilled, combusted locally, or traded short distances, mainly cross-border. Landfilling has been the primary way to deal with wood waste, e.g. in North America. Nowadays though, as, e.g. in Canada, wood waste is increasingly used as process fuel in industry (e.g. pulp and paper) or as wood pellet feedstock [44]. In Europe, wood waste has been combusted and traded for energy purposes within the EU and between EU MS and their border countries for over 15 years. Currently, about a third of all recovered wood in Europe is being used for energy purposes, i.e. over 10 Mtonnes per year [56].

EU trade movements (see Section 4.3) started in the late 1990s when an increasing amount of wood waste was collected, yet few combustion plants had sufficient equipment installed to fulfill flue gas cleaning requirements, let alone monitoring devices to prove compliance (see [55] for a legislative overview). Many Swedish large scale district heating plants however at that time had flue gas monitoring devices already installed [29,40]. This created sufficient opportunity costs for trade streams of recovered wood from many EU MS to Sweden. Other and recently more important drivers for EU trade with recovered wood are the differences in legal and bioenergy policy frameworks across the MS. To minimize transportation costs, waste wood is generally crushed (at least partly) before export [57].

3.5. Charcoal

World charcoal (*HS 440200*) production has grown from 36.7 Mtonnes in 2000 to around 47 Mtonnes in 2009 [26] (see Table 14 in Appendix 2). Key producers have been Brazil (18%), Nigeria (8%), Ethiopia (8%), India (5%), and China (4%). Apart from traditional heating and cooking (including barbeque in industrial nations), charcoal finds application in the chemical (as active coal) and in the iron and steel industry (as a reducing agent and energy source). Brazilian's charcoal production and demand increase has primarily been linked to the industrial sector, foremost the production of pig-iron [6]. World charcoal trade has grown from 0.85 to 2.2 Mtonnes between 2000 and 2009, i.e. 2–5% relative to production [26,27]. International trade has been dominated by Germany (10%), Japan (9%), and South Korea (8%) in terms of imports. Poland is the largest source for charcoal trade to Germany, followed by Paraguay and Argentina. Japan and South Korea tend to source their charcoal mainly from Asia, i.e. Indonesia, Malaysia, and China. Total world exports have been lead by Paraguay (14%), a quarter of whose trade is directed to Brazil; smaller volumes have gone to Spain (6%) and Germany (3%). Indonesia (13%) is the second largest exporter of charcoal. Its trade has been directed towards South Korea, Norway, and Japan. A general observation is that China's trade involvement (both import and export) has grown rapidly in recent years.

So far, international charcoal trade takes place in bagged form. No international technical standard for large-scale bulk transport is available [39].[7] This implies that the traded charcoal is of high quality (chemical industry) and/or for high priced consumer end-markets (e.g. BBQ). It also means that no direct, large scale trade for modern energy conversion has been taken place yet. Current trade for energy purposes is limited to heating, cooking, and barbeque, i.e. is not policy related.

[7] Such standards are required due to Health and Safety regulations. Solid biofuels in bulk may cause off-gasing and self-ignition.

3.6. Agricultural and industrial residues

According to Johnson et al. [6], agricultural residues contribute 3.5 EJ (7%), industrial woody residues about 6.1 EJ (12%) of global primary bioenergy annually. The largest share is traditional heating and cooking. Residue usage in modern bioenergy and interconnected trade is a new phenomenon and interviews revealed that policy inflicted trade was exclusively related to EU import (see Section 4.4). On a global scale, agricultural and industrial residue trade streams under chapters *HS 12*, *18*, *23* show a constant, i.e. non-correlated development to bioenergy policy introductions (see Fig. 1). Therefore, global statistics [27] were not deemed to be able to provide additional energy related insights and were not examined further. It appears that the majority of residue streams have been traded for animal fodder. This especially applies to industrial residues from starch, sugar, and vegetable oil production. The bulk of traded solid residues of the palm oil industry (*HS 230660*) for example is palm kernel expeller, a sought-after feed-adder in livestock production. Historic exceptions such as tapioca pellet combustion are regarded as marginal since the value for protein is assumed to remain higher than for energy.

4. Global solid biofuel trade

Section 3 reveals that Europe has been the prime market for energy related biomass trade over the past decade. This trend appears to be directly linked to recent energy policies. Trade patterns are therefore investigated with an EU-specific focus in this section. Due to their international expansion, wood pellet trade is investigated globally. Trade in charcoal is omitted since it does not appear to be related to bioenergy policies.

4.1. Fuelwood trade – EU focus

Imports of fuelwood into the EU have increased by roughly 1 Mtonne since 2000, reaching almost 1.16 Mtonnes in 2010 (see Table 6 in Appendix 2). The increase can partly be attributed to the EU enlargement. Exports to third countries though have stagnated across the same period. Italy has dominated EU imports over the past decade, largely sourcing from the Balkan and its border states (see Fig. 4). By 2010, Sweden had become the largest importer, followed by Italy, Belgium and Germany (see Table 7 in Appendix 2). Belgium almost solely imports from France. Germany sources from its neighboring countries and Latvia. Swedish imports are also dominated by Latvia; the distribution of imports suggests that most trade takes place via ship (see Fig. 4). EU trade statistics [28] reveal a gap of over 1 Mtonne between intra-EU imports and exports (see Table 7 in Appendix 2), suggesting that volumes are declared differently at origin and destination (e.g. trade between France and Belgium). In general, the European fuelwood trade shows signs of re-exports and/or switch of local fuelwood with cheaper imports allowing exports to higher priced markets; e.g. in Hungary and Slovenia (see Fig. 4).

The majority of EU fuelwood trade is for residential heating. Industry sources though indicated that fuelwood (of 1 m in length) has also been imported from Russia by large energy utilities in minor volumes in 2010 [58].

4.2. Roundwood and wood chip trade – EU focus

Roundwood and wood chip trade for energy are interlinked since both end up in similar conversion facilities with roundwood being chipped at the plant. Despite larger handling costs, importing and chipping roundwood allows quality and size control of the wood chips; also, there are benefits in terms of storage

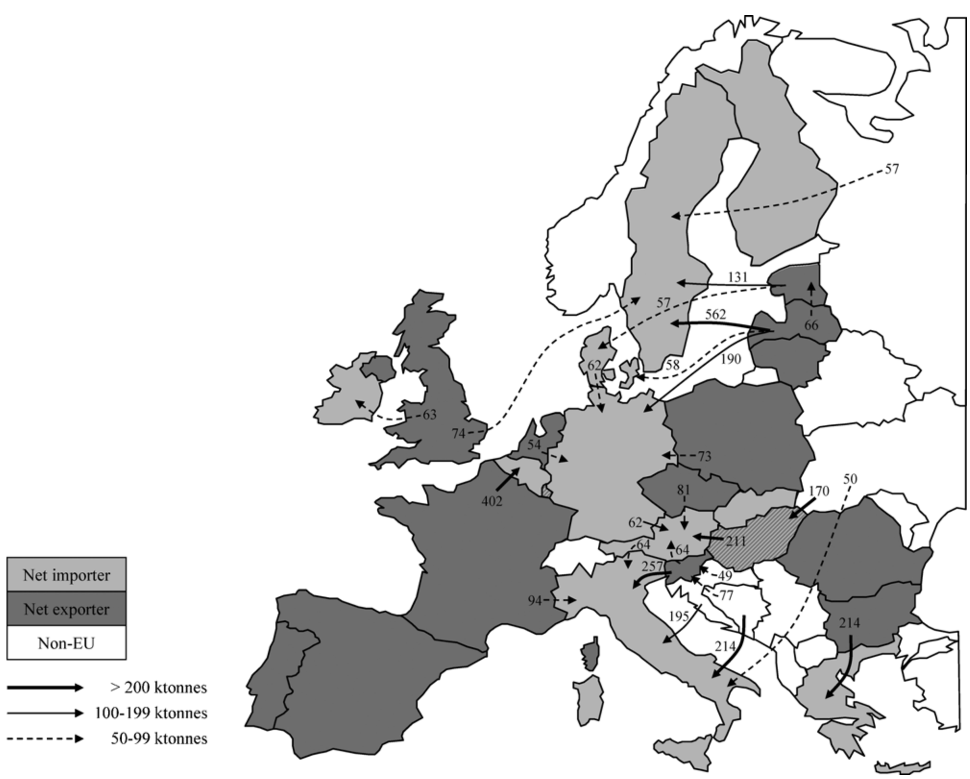

Fig. 4. EU fuelwood trade streams (>50 ktonnes) in 2010 based on *CN 44011000* in [28]. *Note*: Numbers are maximum annual volumes, i.e. may be based on import or export data. Exports may include re-exports.

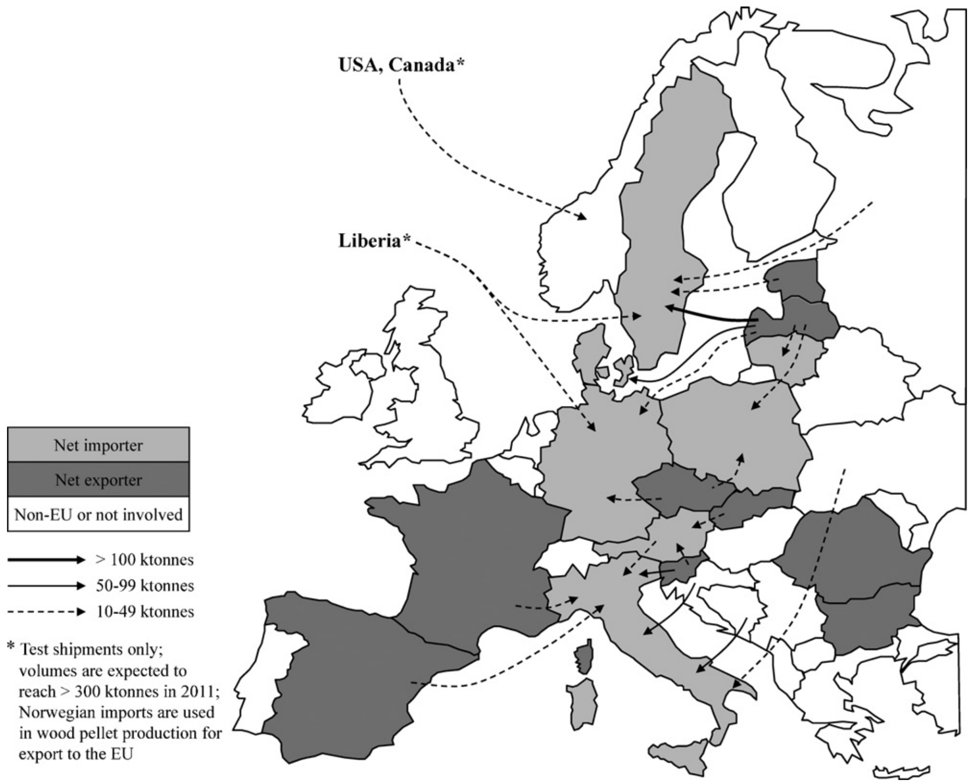

Fig. 5. Bioenergy related wood chip trade patterns in 2010 based on [20,27,28,40,57,60–62]. *Note*: Trade streams towards Denmark, Germany and Sweden are also indicators for roundwood trade volumes and routes.

(moisture, heating value) [59]. Generally, both commodities are directly traded between supplier and consumer and volumes are delivered straight to the combustion plant via ship – especially in Scandinavia. Typically, they are also transported together on the same vessel [57,60]. Low water levels – especially in Baltic harbors – do not allow the landing of large open-sea going vessels and therefore limit trade options primarily to short-sea shipping (3–10 ktonnes) [57,60,61].

Industry sources indicate that Germany, Denmark, and Sweden have been the leading importers of lower priced/quality roundwood for energy purposes over the last decade; sourcing largely from the Baltic States [59]. Due to yet still valid export duties and longer transport distances from forests to harbors than in the Baltics, it is questionable that Russia also exported significant amounts of roundwood for energy to these markets [24,59,60]. Bioenergy related wood chip trade is particularly important to Sweden and Denmark from Russia and the Baltic States [20,39,40], and to Italy, e.g. from the Balkan [61]. All three countries use wood chips mainly in medium scale (CHP), fluidized bed installations. Sweden is most likely the largest EU consumer of wood chips for energy purposes [57]. While it tends to source them mostly domestically, imports rose sharply due to harsh winter conditions in 2010/2011 [40].

Recently, cold winters with ice in Baltic Sea supply harbors led to increasing roundwood imports from Southern Europe to Denmark and Sweden [59]. So far though, no extra-EU imports of roundwood for energy purposes are known. This is different to wood chips which have been imported to Norway from North America (and also from Brazil and Africa) where they are used in pellet production [39,62,63]. Operations started in 2010, i.e. only small volumes have yet been traded. Eventually trade is expected to increase tenfold, reaching approximately 330 ktonnes per year [62]. The same applies to imports of wood chips from Liberia where energy utility Vattenfall has engaged in operations to chip (and replant) unproductive rubber trees and combust them in co- and mono-firing facilities in Europe [64]. In 2010, 37 ktonnes were imported under the trade category of waste wood (*CN 44103080*) [28]. This nicely illustrates the ambiguity of solid biofuel trade declarations.

Generally though, roundwood and wood chips for energy purposes have been transported over shorter distances than, e.g. wood pellets (see Section 4.5). Apart from vessel size restrictions in the Baltics, this is primarily due to the ratio between moisture content, heating value, and bulk density as compared to wood pellets [10,20,39,61]. In addition, the EU currently requires phytosanitary measures for softwood chips from North America. The additional costs have ultimately limited softwood chip trade to high quality chips designated for pulp and paper production (higher margin) [65] (Fig. 5).

4.3. Waste wood trade – EU focus

As pointed out in Section 3.4, early waste wood trade in the late 1990s was targeted towards Sweden. By 2010, waste wood combustion in dedicated plants or in co-combustion with wood chips and industrial pellets has become common practice in more MS leading to a flourishing EU-wide trade (see Fig. 6). The Netherlands and the UK are the largest exporters of waste wood to other MS (see Table 9 in Appendix 2). Sweden remains to be a net importer but trade to other MS is far larger these days (see Table 9 in Appendix 2). Key destinations include Germany, Belgium, and Italy (see Fig. 6). Germany also ranks among the top exporters and shows a balanced import-export relation in comparison to other MS (see Table 9 in Appendix 2). This is largely due to the fact that the existing RES electricity feed-in scheme has been providing strong incentives for the combustion of clean (non-treated) waste wood. In the past, more contaminated waste wood had, e.g. attracted more subsidies in the Netherlands [66]. Germany therefore imported eligible and exported non-eligible wood waste streams.

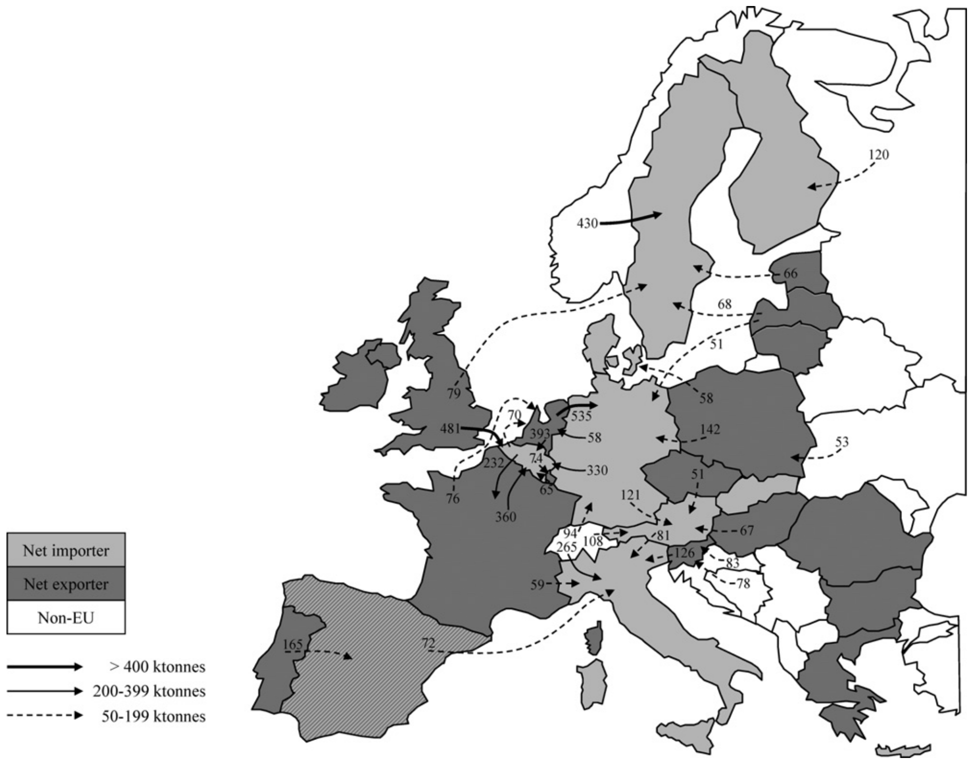

Fig. 6. Waste wood trade streams (>50 ktonnes) across Europe in 2010 based on *CN 44013080* in [28]. *Note*: Numbers are maximum annual volumes, i.e. may be based on import or export data. Exports may include re-exports.

Looking at the overall intra-EU trade balance (see Table 9 in Appendix 2), it is striking that the trade quantities reported at the origin differ from those at the destination leading to a significant gap between imports and exports (Fig. 6 shows maximum reported volumes). Overall, the EU is a net importer of waste wood with an active cross-border trade to Switzerland and Norway, the two key import and export destinations. Other relevant origins include Russia, the Balkan, and the Ukraine (see Fig. 6 and Table 10 in Appendix 2).

4.4. Residue trade – EU focus

Residue markets, e.g. palm kernel shells (PKS) have developed from the supply side, i.e. via an oversupply/local under-utilization of available residues from existing industries [61]. Generally, international trade can and has served as a means to build up logistics infrastructure and local capacity. Afterwards residue exports (e.g. PKS) can be and have been switched back to supply local industries [61].

The first large scale shipment of palm kernel shells (PKS) was from Indonesia to Italy [67] in 2004. In Italy, and later also in other MS, PKS have been co-fired with woody biomass in fluidized bed combustion systems. Their valuable characteristics (high energy density, low moisture content, slow organic degradation, etc.) make co-firing with coal an interesting option. Due to this fact and their relative abundance in palm oil producing countries, foremost Indonesia and Malaysia (partly also Thailand, Nigeria, and Ghana), exports to the EU (still primarily Italy) quickly rose to an annual volume of 200–400 ktonnes [61,67]. In 2007 however, the oversupply of woody biomass (due to heavy storms) and wood pellets caused a significant drop in import volumes. It was not until 2009, when trade volumes were significant quantities again, i.e. around 50–100 ktonnes to Italy, UK, and Sweden. At that point however, domestic use and demand in other Asian markets had increased. In 2010, shipments to Japan were between 30 and 40 ktonnes and South Korea well above 40 ktonnes [61].

Apart from Indonesia and Malaysia, smaller shipments of PKS to the EU were made from West Africa in 2009–particularly to Sweden. The reduction in transport distance made it viable to use smaller ships which are able to access Baltic Sea harbors. The markets for PKS in the EU clearly depend on the combustion technology. PKS milling is partly still problematic for existing equipment but a requirement for co-firing in pulverized coal power plants. Also PKS supply is uncertain with demand increases in Asian markets (especially South Korea and China) [39,61], limited West African supply and unreliable harbors, and a general dependence on global palm oil demand developments. PKS also face significant competition from wood pellets since these are currently cheaper and connected to fewer uncertainties [39].

In addition to PKS, there have been other smaller residue trade streams. Examples included olive kernels from Northern Africa (Morocco, Algeria) to Sweden in the range of 50 ktonnes per annum [40] or rice husk pellets from Vietnam to Europe and South Korea [68]. Other single batch examples were 3 ktonnes of coffee shells to the Netherlands from Brazil in 2007 for co-firing [39].

4.5. Wood pellet trade – global developments

As shown in Fig. 7, EU production, demand, and imports have increased more than tenfold since 2000; clearly driven by EU and MS policies. Production and import patterns have developed in accordance with the respective consumer markets. Most pellets in the EU have been combusted in residential heating (dominated by Italy, Germany, and Austria), followed by district heating (Sweden and Denmark), and large scale power production (almost solely in Belgium, the Netherlands, and the UK) [23,69]. Different

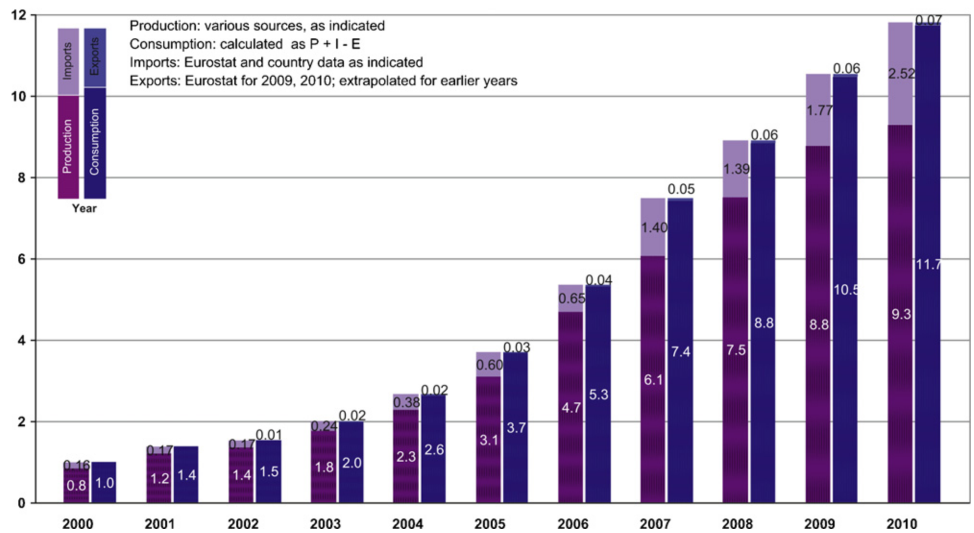

Fig. 7. EU wood pellet trade balance (only extra-EU trade) in Mtonnes based on [11,19,21,23,28,42,43,45,46,54,70,71].

pellet types are used and traded across these markets (see Fig. 8, Tables 12 and 13 in Appendix 2). Whereas (EN/DIN) normed, sawdust derived, high quality pellets are supplied in bulk or bagged to the residential heating market; large scale district heating and co-firing installations predominantly use industrial quality pellets derived from bark and other low(er) value feedstock.

As can be observed from Fig. 8, intra-EU trade of industrial wood pellets is mainly via vessel from the Baltic states and Finland to Denmark, Sweden, and the UK (see also Table 13 in Appendix 2) [20,28]. High quality pellets trade is mainly oriented towards Italy and sourced from Germany, Austria, and Slovenia (by truck), as well as from Portugal and Spain (by ship) [20]. Further (intra- and extra-EU) trade of high quality pellets takes place by truck over short distances, often just cross-border, e.g. Germany–Austria–Switzerland or Norway–Sweden [20,21]. Extra-EU imports have been dominated by industrial pellets [69], mainly from Canada, the US and Russia (see Table 12 in Appendix 2). North American trade is primarily destined for markets in the Netherlands, the UK, and Belgium (see Fig. 8). The majority of Russian exports enter the EU in Sweden or Denmark (see Fig. 8).

Extra-EU imports reached 2.5 Mtonnes, i.e. over 20% of EU consumption in 2010 (see Fig. 7, Table 12 in Appendix 2). Prior, the share of extra-EU imports ranged between 12 and 18% (see Fig. 7). Intra-EU trade shows a significant data gap between total EU-internal imports and exports (see Table 13 in Appendix 2). One underlying reason might be that intra-EU imports include

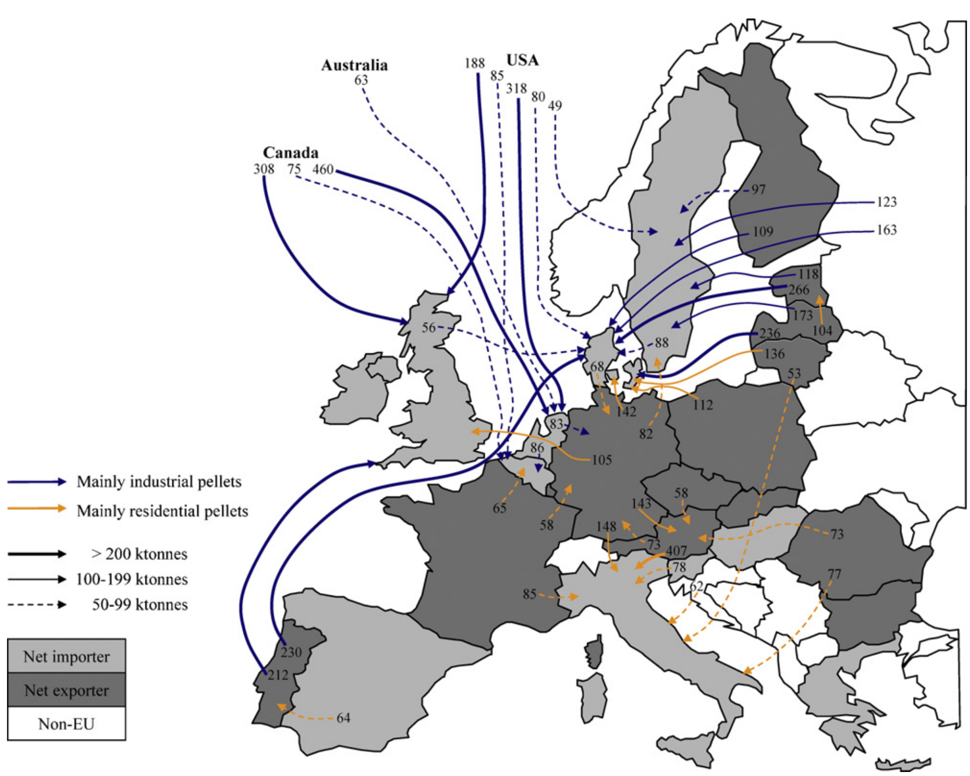

Fig. 8. Main wood pellet trade streams (>50 ktonnes) in Europe in 2010 based on *CN 44013020* in [28]. *Note*: Numbers are maximum annual volumes, i.e. may be based on import or export data. Exports may include re-exports.

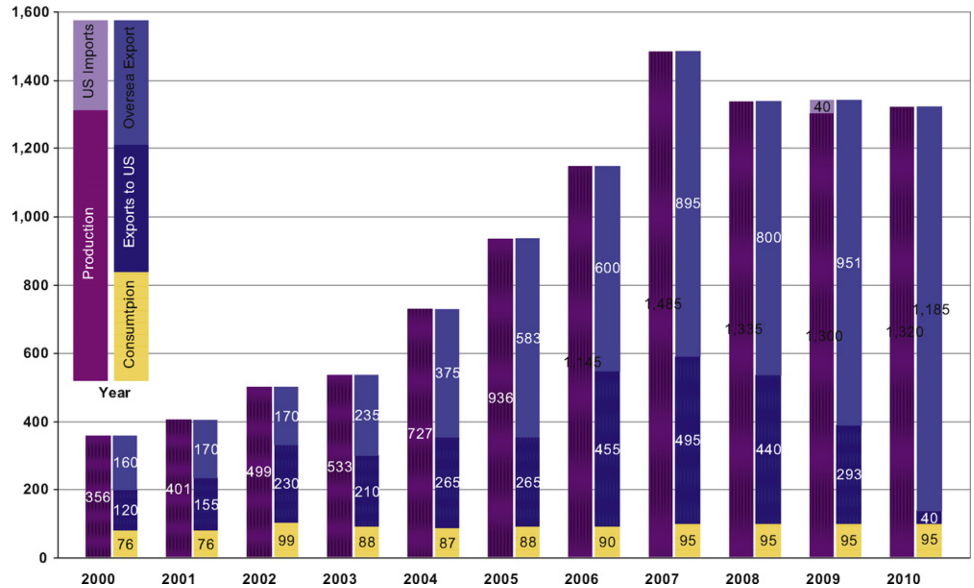

Fig. 9. Canadian wood pellet trade balance in ktonnes. *Note*: EU import and Canadian export data for 2010 show a data gap of around 100–150 ktonnes. This is attributed to reporting delays in Europe and part-time storage in Canadian and EU harbors based on [11,21,23,28,38,42,43,46,48,71], and own calculations.

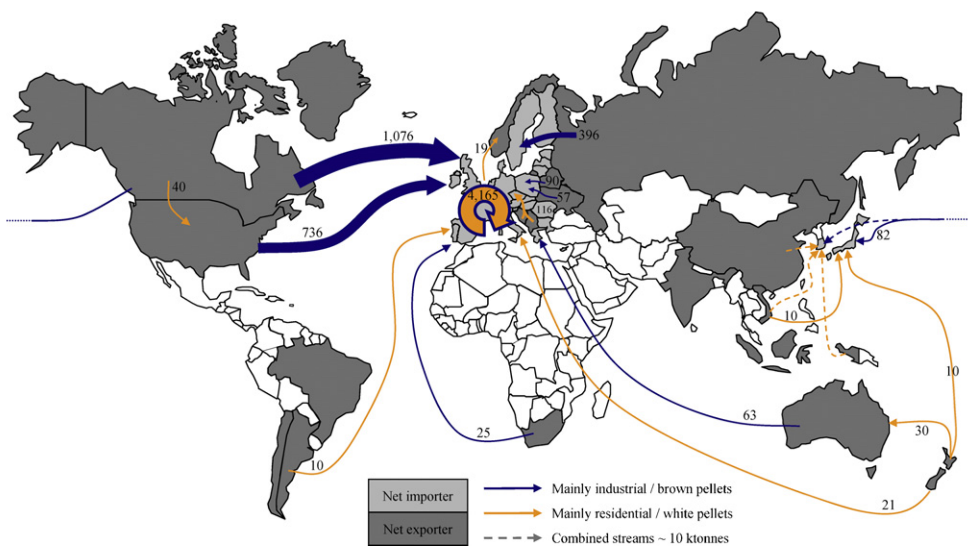

Fig. 10. World wood pellet trade streams above 10 ktonnes in 2010 based on [28,38,42,44,47,48].

re-exports as some indicated exporters (e.g. the Netherlands, Belgium) have limited own production but transfer oversea imports through their harbors.

Historically, wood pellet production in *North America* had been based on surplus sawmill residues and focused on the residential heating market. Canadian producers though quickly also began exporting. At first primarily to the US, but with the expansion of the US natural gas grid in the late 1990s increasingly to offshore markets [11]. The effect of the decline in the US housing boom in 2008 is clearly visible in the reduction of Canadian pellet exports to the US (see Fig. 9). For most of the past decade, Canada dominated North American exports to Europe (see Fig. 9).[8] US exports though have increased sharply in recent years (see Table 12 in Appendix 2) fuelled by the installation of new, large scale units in south eastern states, whose production is exclusively aimed at the EU market. In 2011 alone, an additional 1.55 Mtonnes of wood pellet production capacity are expected to start operation in this area [42,51]. The plants will use an increasing share of roundwood and forestry residues; an industry trend which can be observed since 2008/2009 when the decline in the US housing market and the global financial crisis lead to reduced demand for sawn wood and thus sawmill residue output [45]. As of 2009, the US Biomass Crop Assistance Program (BCAP) has further contributed to this trend by promoting the use of unused forestry residues. The new US plants have several key advantages over their Canadian competitors: scale, location/proximity to the main export market (currently the EU) and BCAP subsidies at a maximum of US$ 45 per tonne of wood pellets [42]. Thus, Canadian producers have already started to investigate new export destinations – foremost South Korea and Japan.

In *Japan* and *South Korea* domestic pellet demand largely consists of residential heating, industrial type boilers, and co-firing for power generation. It is estimated that both markets will follow a

[8] Around 65% of the Canadian production and capacity (average plant sizes of 150 ktonnes) is located in British Columbia; 90% of all Canadian oversea exports originate here [43].

similar pattern as the EU, i.e. due to the quality and price differences, local (high quality) sawdust pellets will be used in residential heating, waste wood derived pellets in boilers and imported (industrial type) pellets in co-firing [48–50]. The latter has already played a major role in the steady increase of imports. Japanese wood pellet imports had been below 20 ktonnes until 2007 but are expected to reach over 80 ktonnes in 2010 [38]. Mitsui, e.g. will import more than 400 ktonnes of pellets over the period 2010/2011; aiming to sell to Japanese energy utilities [49,50]. Nevertheless, since Japanese coal power plants are mostly fluidized bed, wood pellets will compete with wood chips [43]. Current key import region for wood pellets is Canada (80% in 2010), followed by Vietnam (12% in 2010) [38]. South Korean imports were around 7.4 ktonnes in 2009 and expected reach over 10 ktonnes in 2010 [48]. National production and imports are expected to grow faster than in Japan since the first intermediate target of the Renewable Portfolio Standard will be due by 2012 [48]. South Korea is also financially supporting and engaging in South-East Asian developments (e.g. in Indonesia and Cambodia) to develop bioenergy plantations and pellet production [48].

Russian pellet production started around 2001 from very small scale [52]. It has grown steadily ever since and reached 840 ktonnes in 2009 [23]. Its key market has been the EU; domestic consumption remains to be relatively small. Despite its prominent production and feedstock potential, the Russian pellet industry has not yet reached the sizes of, e.g. US, Canadian, or Swedish production. Key hurdles have been the investment climate and the mobilization of the forestry potential (due to a lack of infrastructure) [19,33,70]. New pellet plants are under construction, among others one of the world's largest with a theoretical capacity of 900 ktonnes based on roundwood, bound to start operation in 2011 [51].

Production of wood pellets in *South America* has so far been limited to Chile, Brazil, and Argentina. First investments were made in 2006/2007 when a continued price increase on the EU pellet market was expected [72]. Prices however stabilized by late 2007 (and even dropped in consecutive years) and production volumes therefore never grew beyond 2007 levels [21,39,72]. Currently, no production of industrial pellets is known. South America has not yet become a significant pellet supplier/exporter despite a large technical potential, i.e. raw material (residues and plantation wood, especially in Brazil) availability via well-established wood and paper industries due to a lack (or halt) of investments and competition with other (cheap) international exporters to the EU.

In *Australia*, wood plantations have been primarily grown to deliver feedstock for pulp and paper production [40]. More recently, the focus has shifted towards the export of energy related wood products, foremost pellets. Large scale production of industrial pellets for export started in 2009 and was expanded in 2010 when a few shipments went to the EU [28,39]. In 2011, production and exports came to a halt. So far, the installed capacity (250 ktonnes) has not been fully utilized as the industry has seen cases of bankruptcy and still tries to overcome early market issues (including lack of organization, technology, concern for clean wood, use of technology) [40]. Small scale production of high quality wood pellets for the residential heating market in Australia (supplemented with New Zealand imports) exists but is still only at around 5 ktonnes installed capacity [47]. *New Zealand*'s production has grown strongly in recent years, reaching over 100 ktonnes in 2010–20 ktonnes of which were destined for domestic use [47]. The remaining share was exported to Australia, Japan, and the EU. The future markets for Australian and New Zealand pellets are believed to lie in Asia (South Korea, Japan, China). Apart from the transport distance advantage, the EU market for industrial wood pellets is currently a buyer's market, i.e. most extra-EU imports are low priced volumes from Canada and the US via established trade routes [39].

South Africa has also seen a plantation oriented wood fuel and pellet production for export [6]. However, out of three companies operating in 2009, two went bankrupt while the remaining market party is not operating at maximum capacity due to problems with impurities (e.g. sand) [39] (Fig. 10).

4.6. Global net solid biofuel trade

This section derives global net solid biofuel trade, i.e. direct trade volumes of biomass commodities for energy purposes which might have been impacted (triggered or steered) by policies, i.e. wood pellets, fuelwood, wood chips, waste wood, and residues (see Section 5 for details). All calculated individual solid biofuel trade volumes remain well below the global upper limit as reported in COMTRADE [27].

The methodology for global net wood pellet trade builds on the central observation (based on past developments) that the most lucrative markets – from a producer's and trader's perspective – are in the EU, and to some extent also in the US, Japan, and South Korea due to the (partly policy influenced) local market value for pellets. The respective trade data was collected from [23,28,38,39,44,45,48,52]. There is little risk for double-counting in this approach since the markets are yet still very separated; apart from EU internal distribution of extra-EU imports. Large scale shipments though are often directly from the producer to the end-user. Adjustments were made for shipments going through Rotterdam and trade from the Balkan to Italy via Slovenia (in the range of 240 ktonnes p.a.). Associated trade of raw material for wood pellet production, i.e. primarily roundwood (sawdust and bark) and waste wood is neglected as the main pellet producing nations are key roundwood suppliers (i.e. do not depend on imports), and waste wood as well as direct roundwood to pellet conversion are only at initial industry stages and the respective facilities all own local forestry plantations.

As for wood pellets, the main energy policy influenced markets for fuelwood and waste wood are deemed to be in the EU. Therefore, their trade volumes encompass EU imports and EU internal trade. Both can be collected from EUROSTAT [28] though wood waste data for the year 2008 and prior also includes data on pellets. Hence, an extrapolation was made on averages between linear and exponential growth cases assuming that intra-EU trade has started to level off while extra-EU imports might still increase (see Fig. 12 in Appendix 2). Naturally, the uncertainties underlying such extrapolations have significant effects on the sensitivity of the overall global net solid biofuel trade volumes.

International wood chip trade for energy purposes was assumed to be exclusively towards the EU. Annual trade data was based on anecdotal evidence and literature [20,29,40,57,60–62]. Furthermore, it was assumed that the relative fluctuation in trade volumes follows those of residue trade since the final applications of either stream are fluidized bed boilers. In this regard, both streams have to compete with alternative fuels, e.g. wood pellets. Since trade within those two markets occurs primarily directly between seller and buyer, re-exports play a marginal role and were neglected. Roundwood for energy has almost exclusively been traded via the Baltic Sea where loads are often combined with wood chips, creating a direct correlation. Roundwood trade is deducted using a 50–50 load ratio between wood chips and roundwood for wood chips trade flows between Baltic countries and Denmark, Germany, and Sweden.

Trade in residues, primarily PKS, is also targeted towards the EU, but increasingly also towards Asian markets. Annual trade volumes are exclusively based on anecdotal evidence and literature [39,61,67], and personal assumptions. Global PKS trade is estimated to range between 1 and 3 Mtonnes (18–54 PJ), assuming that Indonesia and Malaysia are the main sources due to accessibility,

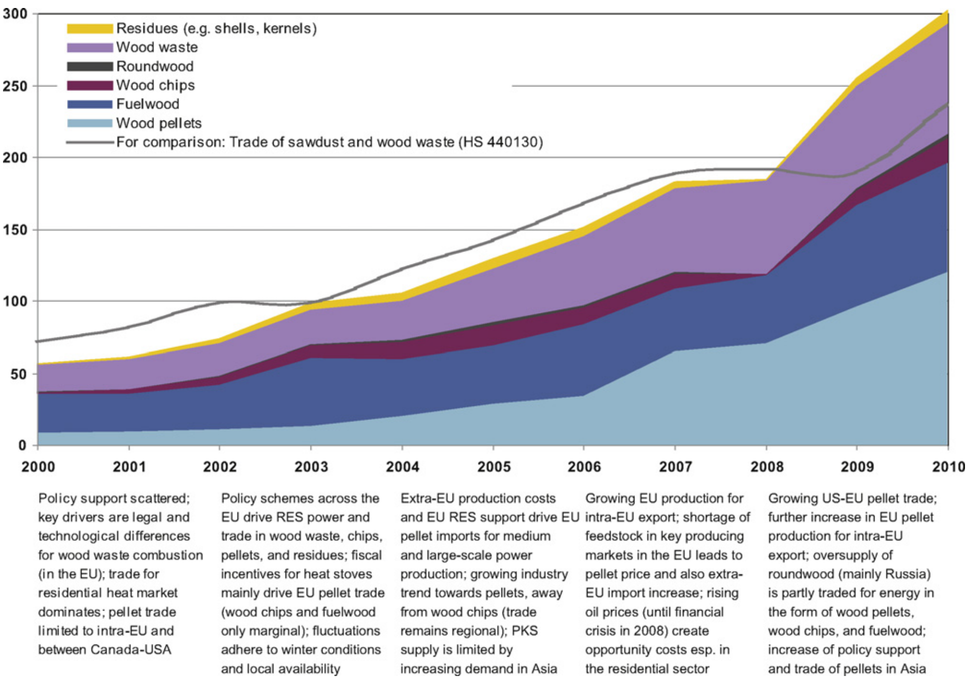

Fig. 11. Global energy policy related net solid biofuel trade in PJ (own calculations based on [23,26–29,33,38–40,44,45,48,52,55,56,60–63,67]). *Note*: Global trade under commodity code *HS 440130 Sawdust and wood waste* is only included for comparison purposes; its 2010 value is an extrapolation of the 2009 relation between wood pellets and HS440130.

a ratio of 19–30% PKS to palm oil, and 25% being traded internationally with 50% being used locally and the remaining share to be inaccessible [61,73]. This estimation includes smaller trade volumes such as barge shipping between production fields and local combustion facilities. Compared to this, energy policy-influenced trade is – as for other solid biofuels – yet small, i.e. around a third of global trade in the case of PKS.

5. Policies and market factors shaping international trade

Global direct trade in solid biofuels towards markets influenced by energy policies has strongly risen over the past decade (see Fig. 11). However, trade patterns of the analyzed commodities have developed differently. This implies foremost that they were either exposed to different stimuli or/and show different characteristics.

In terms of *market* characteristics, it is obvious that the dominant producing and exporting nations are those with long-standing, export-oriented forestry, wood processing, and/or pulp and paper industries. The availability of residues, i.e. no/low cost raw material [61], the possibility to use existing infrastructure (for processing and transport), and interconnected know-how have turned out to be key drivers and success factors. This is particularly true for regions where domestic policies have triggered national bioenergy markets, as, e.g. in Scandinavia or Austria. Countries with little domestic interest in bioenergy, due to, e.g. fossil fuel surpluses (e.g. Australia, Russia), have shown that the existence of aforementioned key factors under absence of strong national interests is not necessarily a guarantee for success. Slow and inconsistent developments in young markets with a high theoretical biomass potential (see, e.g. [74]) further exemplify the need for local experience and continuous domestic interest for market off-taking. Reliance on existing knowledge however also implies that there has been little innovation across the industry [40].

Early demand side developments took place in countries with existing businesses, i.e. combustion facilities which could be switched to co-/mono-firing solid biofuels. This has been particularly prevalent in markets dominated by fluidized bed combustion technology and low cost residue potentials (e.g. forestry residue usage in district heating in Sweden). Feedstock demand of these installations practically initiated all first large trade streams other than fuelwood and high quality wood pellets. It is found that key drivers for early waste wood trade were EU requirements for emission monitoring technology (which was not installed in some markets), whereas differences in national policy frameworks create important drivers for wood waste trade to date (see also [66]).

Key defining factor for international solid biofuel trade is economic viability. On the supply side, it is constrained by production and transport costs; in turn mostly influenced by feedstock, vehicle costs, and biofuel characteristics [25]. The heating value (correlated to moisture and ash content [75]), bulk density, (homogeneous) form and chemical composition define the monetary value of the biofuel. These factors determine whether a commodity is worth transporting over long distances (via ship), relatively more expensive (short) transport modes (e.g. via truck), or whether it requires further processing (e.g. drying, pelletizing; see also [76]). Low heating value products (e.g. forestry residues) with a relatively low monetary value are usually used locally or transported cross-border. Refined, homogeneous biofuels with a high heating (low moisture and ash content) and monetary value (e.g. bagged wood pellets for residential heating) are traded globally. A high bulk density is preferable for long or expensive transport and is clearly influenced by processing (e.g. condensing into wood pellets) (see Appendix 3). Furthermore, biofuels with high flow-abilities (e.g. wood pellets) may be transshipped using existing handling equipment and storage terminals, whereas low/no flow-abilities (e.g. wood chips, bark, fuelwood) may require additional investments [77].

On the demand side, economic factors driving trade are margins in end-consumer markets, potentially influenced by policies (see below), exchange rates (see [25]), and application scales. Economies of scale allow trading of low quality/value commodities; particularly those with similar combustion characteristics to

coal or which can be used in various combustion facilities, e.g. PKS (Table 2).

RES support *policies* can take on various forms (see [78] for a review). They are able to influence markets on the supply and demand side, plus trade via tariff policies and regulations. So far, the latter category has been largely irrelevant for the commodities in focus.[9] There is however an EU requirement for phytosanitary measures for wood chips from North America which practically eliminated trade for bioenergy along this route. Also, EU timber regulation 995/2010 [79] demands due diligence for wood (products) placed on EU markets. This includes (energy related) commodities under chapters *4401* and *4403* except waste wood; thus indirectly incentivizing trade under code *44013080*.

On the supply side, policies aim at reducing production costs, i.e. mainly for feedstock and processing in forestry/agriculture (see [80] for EU forestry sector support). This includes indirect stimuli via R&D (e.g. forestry management practices) or direct financial incentives for (collection, handling, or processing) equipment, the provision of otherwise unused residues, or the planting of dedicated cellulose crops. An example for the latter is the US BCAP which – in its initial stage – even led to residues being taken away from existing uses causing a revision to now support unused excess residues only [81]. Supply side policies have primarily stimulated domestic markets and yet had marginal effects on trade increase.

This is different to demand side policies which have significantly stimulated international trade. The developments in the EU nicely illustrate the varying policies and their effects (see [82,83] for a detailed discussion of EU RES policies). In the residential heating market, direct and often single fiscal incentives in the form of, e.g. low interest grants, loans, or tax rebates have stimulated installments of biofuel stoves/boilers (see Table 3). These incentives were especially effective in markets with mature boiler/stove industries and where biofuels were price competitive (on a heating value basis) with other heating fuels, i.e. LPG, oil, and partially natural gas and electricity (see, e.g. [84]). In Germany, e.g. consumer prices for pellets ranged between 120 and 200 €/GJ compared to 140–200 €/GJ for fuelwood, 50–115 €/GJ for wood chips, 115–330 €/GJ for heating oil, or 160–300 €/GJ for natural gas from 2003 to 2010 [85,86].[10] Price prognoses in the residential market though are yet practically non-existent or relatively short-term [23] and regional feedstock price fluctuations have caused stove/boiler sales to drop temporarily – e.g. for wood pellets in Austria in 2006 [11]. Thus, (short-term) feedstock prices and stove/boiler choices connected to fiscal incentives defined local biofuel demand. Biofuel trade for the residential market is therefore directly linked to feedstock price advantages. In the EU, fiscal incentives are increasingly replaced with obligations for minimum RES heat shares, e.g. for new buildings in Germany and Italy. This increases competition among RES heating options, i.e. installment and feedstock prices will define future biofuel markets.

In the power and heating market, individual investment support was only relevant for medium-sized, community-owned projects. Rather, the sector has been critically influenced by regulations (quotas, taxes, feed-in schemes) providing long-term framework conditions (see Table 3). Across the EU, all regulation types have proven to be effective [82]. Quota systems, e.g. for RES electricity production in Belgium, Italy, and the UK primarily led to large-scale co-/mono-firing in existing power/CHP plants allowing economies of scale, i.e. quota achievements at minimal costs. Taxation of fossil fuels (e.g. coal in Denmark), partly also connected to quota schemes (e.g. in Sweden) showed similar effects. Imports were strictly related to the flexibility of the respective conversion technology, i.e. wherever possible, various solid biofuels were used in order to broaden the feedstock portfolio and level out price developments. The same has been true for imports under feed-in schemes (FIS), e.g. to the Netherlands, unless they included eligibility criteria as, e.g. in Germany. Pulverized coal combustion plants in Belgium, the Netherlands, and UK have limited the utilized streams to wood pellets whereas dedicated grate and/or fluidized bed facilities (e.g. in Sweden, Italy, Denmark) have sourced a much wider range. Apart from eligibility requirements and prevailing conversion technologies, (partly considerable) margins between commercial break-even point and support levels [82] have influenced trade routes and volumes. Incentives, e.g. under the Dutch FIS equaled break-even points for co-firing at 120–135 € per tonne of pellets and 160 € per tonne of pellets under Swedish taxation levels whereas average industrial pellet prices in bulk ranged between 110 and 150 € per tonne [23]. Moreover, CO_2-pricing under the EU Emission Trading Scheme (ETS) has provided an additional margin.[11] With EU Emission Allowance (EUA) prices between 10 and 20 € per tonne CO_2 in 2007–2009 they averaged 0.012 € per kWh_e, equal to about 24 € per tonne of pellets [23]. CO_2-pricing will continue to play a role in the large-scale segment in the EU; with the ETS going into its third phase in 2013.

6. Reflections and conclusions

Direct global net solid biofuel trade has grown from 56.5 PJ (3.5 Mtonnes) to 300 PJ (18 Mtonnes) between 2000 and 2010. Intra-EU trade makes up two thirds of global trade by 2010. The strongest development over the past decade was observed for wood pellets whose world trade has risen exponentially from 8.5 PJ (0.5 Mtonnes) to 120 PJ (6.6 Mtonnes). Wood waste has become the second largest stream with 77 PJ (6 Mtonnes) by 2010. Fuelwood was the largest trade stream in 2000 but ranked third in 2010 at close to 76 PJ (4 Mtonnes). Its development has been almost linear over the past decade with a sharp increase in recent years attributed to harsh winter conditions in key demand regions in Europe. Other biofuels have been traded in comparatively small volumes: wood chips reached 17 PJ (0.9 Mtonnes), residues 9 PJ (0.5 Mtonnes), and roundwood 2.4 PJ (0.3 Mtonnes) by 2010. Wood pellets have become a globally traded commodity. Trade in wood waste, fuelwood, roundwood, and wood chips for energy is practically limited to Europe. The key markets for residues (shells, husks, kernels) have so far also been in the EU, but trade in Asia is increasing as well. Trade in charcoal could not be directly related to bioenergy policies.

Solid biofuel trade developments of the past decade show a highly heterogeneous picture: wood pellet, wood chip, wood waste, fuelwood and residue trade streams have been driven by various market and policy factors on the supply and demand side. The differences between the market segments limit generic, i.e. commodity overarching conclusions. In general though it was observed that trade was initiated where market factors on the supply side (e.g. excess residues) coincided with emerging/existing demand patterns (potentially overseas). Also, trade flows have been steered primarily by policies (i.e. incentives and regulations) to the most lucrative markets. Trade volumes have been partly restricted by market (e.g. investment in production facilities) as well as policy factors (e.g. legislative changes). In comparison to liquid biofuels

[9] A most-favored nation (MFN) tariff of 0% applies between the members of the World Trade Organization (WTO). No additional tariff preferences for trade between WTO members and third countries were found as part of this analysis.

[10] See e.g. [87] for a detailed comparison of heating costs across different applications in Germany.

[11] Which may be taken by anyone along the supply chain since CO_2 costs have traditionally been passed on to the final consumer.

Table 2
Market and policy factors influencing international solid biofuel trade.

	Stimulating (local) biofuel production/use	Stimulating international biofuel trade
Market		
Market characteristics	Availability of low/no cost excess residues from existing forestry, pulp and paper, or wood processing industries; also allowing the use of the respective infrastructure, know-how, and political influence Preferential climatic conditions (i.e. biomass potential) Existing businesses with facilities allowing biofuel co-/mono-firing; especially fluidized bed technology due to feedstock flexibility	Existing export orientation of the forestry or wood processing industry: infrastructure (railways, harbors), handling equipment (chippers, cranes, etc.), export market/trade know-how Lack of local combustion or emission regulation technology for wood waste burning High local electricity and heat prices increasing the economic viability for biofuel imports Availability of low cost domestic fossil fuels (e.g. in Russia, North America) allowing/stimulating exports of low cost domestic biofuels Limited large-scale, low cost, domestic feedstock production potential
Biofuel characteristics	Local (short-distance) use is typical for biofuels which are either unrefined, cannot be transported in bulk (fuelwood), have a high moisture content, low monetary and/or low heating value (e.g. forestry slash, bark chips) Small margin between supply costs (production and transport) and prices in consumer markets	Refined, homogeneous biofuels with high heating and/or monetary value (e.g. pellets), bulk density, flow-ability (reducing handling costs); low moisture and ash content Large margin between supply costs (production and transport) and prices in consumer markets Similar combustion characteristics to coal (e.g. PKS, torrefied pellets) increasing the attractiveness for co-firing Flexible end-use (combustion technology and scale)
Policy		
Supply related	Incentives to increase the residue use in the forestry and/or agricultural sector, or the planting of dedicated cellulose crops via investment support, direct subsidies, low-interest loans, grants, or infrastructure projects	Overproduction due to lack of local demand, overstimulation and/or highly competitive production prices compared to other international sources incentivizing exports Differing legal requirements for waste wood combustion between neighboring countries
Demand related	Renewable electricity and/or heat targets enforced via regulatory or fiscal policies Emission standards Ban on landfilling wood waste Investment support via low-interest loans, grants, or subsidies for combustion (e.g. pellet boilers) and related equipment (e.g. flue-gas)	Linking domestic policies with eligibility criteria, i.e. limiting the combustion to certain biofuel streams thus increasing respective imports and triggering exports of non-eligible material; the same is true under limited national potential
Trade related	Commodity specific export duties Technical standards, e.g. in the form of phytosanitary measures for imports Hypothetically also sustainability criteria (if fulfilled by domestic production and sufficient, cost and GHG efficient biomass available; or criteria hard to fulfill by international imports)	Avoidance of export duties by transforming the respective commodity Technical standards in the form of globally accepted quality standard (e.g. ENplus for wood pellets) Hypothecially also sustainability criteria (if not sufficient, cost or GHG efficient biomass available in export destination and criteria fulfillment in exporting country is possible)

Table 3
Policy types that influenced solid biofuel production and trade.

Installation scale and type	Small scale, individual residential heating	Medium to large scale, interconnected/district heating and power production systems
Affected biofuels	Mainly high quality wood pellets; to a minor extent wood chips and fuelwood	In order of importance: industrial pellets, waste wood, wood chips, residues
Fiscal incentives		
Grant	XXX	X
Energy production payment	–	X
Rebate	XXX	X
Tax credit	XXX	X
Tax reduction/exemption	XXX	X
Variable/accelerated depreciation	–	X
Public finance		
Investment	–	X
Guarantee	–	X
Loan	XXX (esp. low interest loans)	X
Public procurement	X (solid biofuel heating systems)	–
Regulations		
Quantity-driven		
Renewable portfolio obligation, quota, or mandate	XX (heat)	XXX (heat/power production; biomass consumption)
Tendering/bidding	–	X
Price-driven		
Fixed payment feed-in tariff	–	XXX
Premium payment feed-in tariff	–	XXX
Fossil fuel taxation (CO_2 based)	XX	XXX

Legend: –, not relevant; X, relevant; XX, important; XXX, very important/crucial.
Note: See [78] for a detailed description of the individual policy types.

however (see [7]), (trade) policy changes in the solid biofuel sector had less prominent effects on global trade developments.

Economic viability is a key constraint for international solid biofuel trade. Margins are mainly influenced by production and transport costs, as well as prices in and exchange rates to target markets. The fluctuating CAN/US$-Euro exchange rate has, e.g. heavily influenced intercontinental wood pellet trade. This, in the absences of hedging tools (e.g. a wood pellet forward curve), seriously hampers wood pellet trade. Production costs strongly depend on feedstock prices (whose reduction has been in the focus of several supply side policies). Thus, it is not surprising that the main producing and exporting regions already had a tradition in export oriented forestry, wood processing, and/or pulp and paper industries, and benefited from the availability of low/no cost excess residues, infrastructure, and experience. Transport costs are determined by vehicle costs and availability (e.g. in the case bulk carrier vessels), and biofuel characteristics.

Clearly, wood pellets have become the fastest-growing commodity. Key factors for this success include homogeneity, high heating value and bulk density, and flexible end-use regarding combustion technology and scale. Furthermore, pellet feedstock supply has become more stable, i.e. less dependent on wood processing residues, as producers have broadened their sourcing base (primarily to roundwood and forestry slash). However, these trends may increase competition for woody biomass resources, in particular since international trade volumes are directly linked to (primarily EU-based) demand markets which are bound to increase further in the coming years. Replacement effects have apparently already taken place to a limited extent; e.g. in Austria, where an increase in regional biomass use for energy has led to increased (oversea) imports of the local pulp and paper industry [88]. Production and trade developments of other commodities (e.g. wood chips for energy) have not (yet) shown similar effects. The availability and importance of the respective solid biofuels remain linked and ultimately limited by the developments in their underlying sectors, i.e. forestry/pulp and paper for wood chips and roundwood, construction/recycling for wood waste or food/fodder processing for residues. Apart from feedstock availability, new challenges on the supply side include increasing standardization and sustainability requirements.

On the demand side, markets are diverse and range from single-household wood pellet stoves to combustion facilities of several hundred MW_e. In the residential market, (relatively) short-term price signals and local biofuel availability have defined demand (and trade) patterns. They were stimulated by investment support for boilers/stoves and local price advantages over fossil heating fuels. Biofuels for the residential market have been largely sourced regionally (esp. wood chips and fuelwood). However, price differences (mainly linked to production/feedstock costs) and limited local availability/production have triggered a growing intra-EU trade (esp. fuelwood) and also international imports (esp. wood pellets). Due to the singularity of the support measures, demand in the residential market has been less influenced by policy than in the large scale segment. Here, operational support policies have created long-term framework conditions; primarily aiming at bridging the economic gap towards substitute fuels (esp. coal) which are cheaper and readily available. Trade in the industrial market could therefore be based on longer-term pricing (futures) and increasingly established routes. The latter is also related to a growing vertical supply chain integration of large scale users. While such trends indicate similarities to other commodity markets, e.g. coal, solid biofuel trade still has a long way to go to reach their status/volumes. Trade in the industrial segment is strictly linked to margins, thus policy incentives, and the flexibility of combustion technologies.

Current statistical reporting make global energy related trade patterns still hard to distinguish from other trade flows. Anecdotal data remains essential to estimate and interpret trade flows. Uncertainties encountered in the analysis are mostly linked to (partly large) data gaps. First, reported volumes differ across the databases of FAO, UN, and Eurostat. Second, also within the respective databases, import and export declarations do not always match. The earlier point seems to be linked to differing reporting procedures and the fact that FAO does not account volumes under trade codes but categories. The latter aspect, in particular with regards to the EU, appears to be also related to reporting delays and differing codes used in the country of origin and destination. Interestingly, data gaps vary across individual MS and are smallest in Nordic countries.

While acknowledging ongoing activities to further harmonize trade codes, we believe, datasets should be streamlined across international institutions. Eventually, both efforts would allow reporting of global commodity trade streams beyond digit-6-level (current COMTRADE limit). Building on such data, additional scientific research is required to provide further insights into the still informal trade of solid biofuels. This is particularly the case for evaluating how individual influencing factors on trade interrelate; a crucial component in mapping future trade streams under different policy and potential trade regime scenarios. Such scenarios are important as current policy targets in key markets, the EU in particular, indicate a significant solid biofuel deficit by 2020 (see, e.g. [89]). A further profound trade impact is expected by the commercialization of advanced liquid biofuels (to be used, e.g. in the aviation sector) and the emerging demand of biomass for biochemicals and biomaterial (including, e.g. charcoal for steel production). Hence, we do expect trade to increase strongly over the coming years; despite it constituting 0.3 EJ, i.e. less than 2% of global modern bioenergy use today. Also, future trade is anticipated to become (even) more demand driven; a trend which could already be observed, e.g. in export oriented wood pellet production in South-Eastern USA. Wood pellets are likely to remain the single largest trade commodity, though the cumulative sum of all other biofuels is still larger. In the future, more (cleaned) waste wood and, given options to increase their homogeneity (e.g. via torrefaction), also more agricultural residues are bound to be traded.

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Appendix 1. Background on policies in main markets

European Union (EU)

The deployment of RES is one of the core components of the EU's energy and climate policies. The *Directive on the promotion of electricity produced from RES* 2001/77/EC [90] gave EU Member States (MS) indicative goals and the requirement to implement national support schemes for RES based electricity. Mandatory RES target of 20% in final energy consumption and a minimum of 10% for biofuels by 2020 were implemented via the *Renewable Energy Directive 2009/28/EC* [91]. This meant that earlier targets – for

Table 4
Global industrial roundwood data in ktonnes.

	Production			Import			Export		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
USA	303,017	269,516	243,518	1793	1144	731	7960	8160	7609
Canada	126,087	105,786	84,086	4080	3686	3644	2848	2271	2154
Russia	129,600	109,360	90,320	259	229	48	39,280	29,427	17,360
Brazil	97,216	92,312	97,728	27	16	22	97	94	81
China	72,744	80,674	74,503	30,336	24,240	22,922	43	34	79
Sweden	57,840	51,920	47,360	5892	5425	3340	3046	1879	942
Germany	54,423	37,445	38,458	3754	4606	5759	6139	5630	3364
Finland	41,125	36,772	29,361	10,354	10,697	3009	517	568	427
France	23,853	22,180	22,915	2545	1887	1163	3173	2837	3218
Malaysia	19,995	18,196	16,101	110	173	173	3953	3494	3332
New Zealand	15,931	16,248	16,168	5	3	3	4783	5314	7014
Japan	14,120	14,167	13,295	7178	4982	3304	16	39	31
Austria	13,217	13,417	9715	6978	6040	6429	701	779	583
Others	370,507	375,285	356,000	34,431	26,097	22,699	32,908	31,870	30,212
World	1,339,675	1,243,278	1,139,529	107,742	89,225	73,246	105,464	92,397	76,405
						Data gap	*2278*	*−3172*	*−3159*

Data: [26].

Table 5
Global fuelwood data in ktonnes.

	Production			Import			Export		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
India	84,430	84,640	84,850	1.9	13.3	8.3	0.2	0.5	0.9
China	54,927	53,908	52,907	17.5	9.7	2.0	0.7	0.3	1.3
Brazil	38,454	38,752	39,047	0.1	0.0	0.0	0.0	0.0	0.0
DR of Congo	20,132	20,437	20,748	0.0	0.0	0.0	0.0	0.0	0.0
Nigeria	17,050	17,157	17,268	0.0	0.4	0.0	8.4	1.9	6.2
Indonesia	18,652	17,884	17,144	7.7	11.6	8.7	65.0	56.1	1.6
Russian Federation	12,375	12,293	10,588	0.7	0.0	0.0	97.6	199.0	427.1
France	6811	6884	7003	28.4	23.1	24.3	330.3	300.9	384.3
Ukraine	2618	2618	2618	0.0	0.1	0.2	649.0	589.2	617.4
Germany	2392	2354	2354	286.5	261.1	174.1	31.1	74.1	81.9
Sweden	1623	1623	1623	78.1	102.9	393.0	56.8	76.0	25.3
Turkey	1277	1363	1388	174.3	82.8	46.1	0.0	0.0	0.0
Italy	1412	1560	1370	513.3	597.1	687.9	0.6	0.5	0.5
Finland	1432	1294	1362	97.1	151.0	555.2	5.8	4.2	3.6
Austria	1319	1382	1260	234.4	235.4	503.7	43.0	35.2	68.9
Hungary	792	704	792	148.2	83.8	62.6	132.7	166.1	159.4
Czech Republic	487	517	517	7.1	9.3	17.6	76.8	72.7	93.4
Latvia	283	165	477	7.6	1.2	4.8	338.4	354.0	786.7
Bosnia Herzegovina	368	396	365	0.3	0.3	0.4	312.7	314.5	336.1
Estonia	272	317	317	9.2	5.2	24.4	35.7	74.5	169.1
Denmark	304	304	304	138.8	220.9	171.0	26.1	24.3	41.8
United Kingdom	126	153	272	8.0	14.8	10.9	116.5	75.8	42.6
Croatia	209	210	237	3.1	2.3	3.7	205.3	244.6	267.4
Greece	219	219	219	232.3	274.7	159.0	3.9	1.9	1.7
Slovakia	115	152	161	15.2	57.2	0.0	54.2	52.2	0.0
Other	243,979	242,973	243,760	412	427	538	1361	812	920
World	512,057	510,258	508,952	2422	2585	3396	3952	3530	4437
						Data gap	*−1530*	*−946*	*−1041*

Production data: [26]; Trade data: [27].

Table 6
EU imports of fuelwood in ktonnes.

Country	2000	2008	2009	2010	2000–2010
Bosnia and Herzegovina	6	278	305	310	1811
Russia	133	118	483	121	1800
Croatia	26	219	256	248	1643
Ukraine	4	162	240	388	1300
Albania	0	11	19	35	90
Norway	0	7	11	11	77
Belarus	1	2	9	30	69
Switzerland	9	5	9	8	60
Others	1	13	11	8	
World	179	815	1345	1159	

Data: [28].

Table 7
Intra-EU trade of fuelwood in ktonnes (Data: [28]).

Imports from	2000	2008	2009	2010	2000–2010	Exports to	2000	2008	2009	2010	2000–2010
Latvia	61	272	400	246	2116	Italy	269	381	457	498	4485
Hungary	167	103	217	251	1989	Belgium	169	196	318	460	2769
Bulgaria	149	273	163	235	1736	Sweden	171	99	473	601	2675
Netherlands	12	213	81	77	1248	Austria	218	190	241	239	2462
Slovakia	57	63	97	99	1184	Germany	49	120	339	433	1463
Czech Republic	84	107	139	95	1042	Denmark	67	142	165	147	1266
Estonia	72	41	110	142	937	Ireland	166	77	40	65	1230
Germany	23	83	119	103	731	France	66	117	33	58	1001
Poland	19	88	119	107	695	Greece	29	43	31	38	383
Austria	71	23	26	25	594	Finland	0	126	126	33	374
Others	154	206	369	424		Others	45	214	214	313	
EU27	867	1472	1839	1805		EU27	1248	1705	2437	2883	

Table 8
Global wood chip data in ktonnes.

	Production			Imports			Exports		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Australia	4725	5412	4968	1	1	1	6051	6113	4759
Chile	2384	2583	2293	0	0	0	3065	4059	3695
USA	1513	1925	1650	214	98	57	2996	2861	2849
South Africa	3561	3561	3561	0	1	0	3593	3268	2122
Latvia	751	1024	783	20	80	7	1693	1557	1449
Russia	3273	2420	2035	4	3	2	850	932	1377
Germany	821	776	860	489	341	395	1794	1613	1278
Thailand	572	572	572	1	0	6	359	882	1253
Brazil	2405	1921	1921	1	0	0	1419	1414	1025
Uruguay	352	628	315	0	0	0	959	1697	860
Japan	1280	1430	1556	14,337	14,722	10,478	0	7	0
China	2680	2752	3536	1140	1056	2766	215	73	7
Finland	2579	2188	1596	1661	2432	1908	110	143	227
Turkey	234	234	234	1228	1014	1542	0	0	0
Sweden	4840	4538	4263	1545	1547	1345	518	577	293
Canada	20,725	20,725	20,725	2051	1975	1312	721	551	443
Austria	1510	1472	964	1017	992	1007	440	313	166
South Korea	0	0	0	829	1057	741	0	0	0
Italy	146	146	116	1011	617	691	1	2	9
Norway	0	0	0	616	741	619	28	85	77
Other	7566	7533	7429	4047	4430	3429	3980	3657	3307
World	61,916	61,839	59,374	30,211	31,109	26,305	28,792	29,806	25,194
						Data gap	*1420*	*1303*	*1110*

Production data: [26]; Trade data: [27].

Table 9
Intra-EU trade in waste wood (*CN 44013080*) in ktonnes.

Country	2009		2010		Market share	
	Imports	Exports	Imports	Exports	Imports	Exports
Netherlands	175	1003	152	943	7%	22%
United Kingdom	34	611	31	613	1%	14%
Germany	489	560	612	616	23%	14%
France	200	432	329	549	11%	11%
Belgium	253	286	377	327	13%	7%
Portugal	5	58	10	214	0%	3%
Poland	5	159	11	167	0%	4%
Austria	193	141	236	140	9%	3%
Slovenia	8	113	11	128	0%	3%
Czech Republic	15	125	31	99	1%	3%
Luxembourg	82	95	87	85	4%	2%
Denmark	159	57	110	52	6%	1%
Italy	293	43	378	37	14%	1%
Sweden	83	16	165	8	5%	0%
Finland	58	38	25	15	2%	1%
Other	102	502	115	459		
EU	2152	4242	2679	4453		

Data: [28].

electricity (2001/77/EC) and liquid biofuels (2003/30/EC)[12] – became obsolete; also, the heating/cooling sector was integrated, which, prior to 2009, had no specific target. Furthermore, the Directive 2009/28/EC defines sustainability requirements for the production of liquid biofuels and bioliquids. Solid (and gaseous) biofuels are so far excluded from these requirements [92]. A review of this decision by the Commission is set for the end of 2011.

Across the past decade, EU solid biomass based *electricity production* more than tripled from around 18 TWh (65 PJ) in 2000 to over 62 TWh (224 PJ) in 2009 [82,93]. Typical installations include medium and large scale units (co- and mono-combustion) based on wood pellets, chips, residues and/or waste wood. Many installations cogenerate heat and are connected to district heating/cooling grids (especially across northern Europe and Scandinavia). An increasing share of solid biofuel is combusted in large-scale, (coal-based) co-combustion units with mere electricity output (e.g. in the UK); accounting for 23 TWh (84 PJ) in 2009 [93]. Compared to the electricity and transport sector, biomass based *renewable heat* production only showed a modest growth rate of less than 5% p.a. across the past decade; a development mainly attributed to the lack of a European and partially also national support frameworks for renewable heat [82]. Most support schemes in place focused on investment support in the form of grants, loans, or tax exemptions. Typical installations include small residential ovens (pellet or fuelwood) and medium scale boilers (<20 MW_{th}) connected to heating networks (e.g. for building blocks, museums). The total renewable heat share in the EU is clearly dominated by decentralized (primarily household) heating appliances. Central solid biofuel heating installation (mainly CHP-plants) play a significant role in Scandinavian countries, Lithuania, and Austria [82].

United States of America (USA)

In the US, prior to 2000, federal incentives for RES electricity production were provided via the Renewable Energy Production Incentive and the Renewable Energy Production Tax Credit [21]. In the later years during 2000 and 2008, important developments for the promotion of RES utilization took place exclusively on the *state level* [94]. Introduced policies included financial incentives (e.g. low interest loans), followed by regulatory measures (mainly renewable portfolio standards), and R&D and educational programs [9,24]. Often, the sustainable use of solid biofuels was further regulated via biomass definitions and requirements for forest management practices at state level [24]. In 2009, the *Biomass Crop Assistance Program* (BCAP) was started on federal level. It aims at increasing the use of forestry and agriculture residues via incentives for collection, harvest, storage and transport of biomass feedstock, and energy crop cultivation [24]. Wood based energy production in the US has fluctuated but continuously declined since 1985 from 2835 PJ to 2120 PJ in 2010 [95]. The decline is attributed primarily to a decrease in industrial woody biomass use, especially in the forest products industries [24]. Over the same time period, wood energy consumption in the power sector has increased from 8 PJ in 1985, to 142 PJ in 2000 and about 205 PJ in 2010 [95]. Wood use in commercial building heating systems has been stable over the past decade; whereas it increased over 20% up to 2009 compared to 2000 levels in the residential sector [24].

Canada

The Canadian production of solid biofuels, i.e. primarily wood pellets, has been predominantly export driven (see Section 4.5 for details). National support policies were not yet able to significantly increase the share of local solid biofuel based power production [24]. On state level though, the Ontario Feed-in Scheme, passed as a part of the Green Energy and Green Economies Act (Ontario Bill 150) in 2009, provides technology specific remuneration to various RES electricity including biomass-based power generation. It is expected to be able to trigger new investments including large-scale co-combustion of biomass in coal power plants [24]. Another relevant factor for a potential increase in local utilization is the surplus availability of woody biomass due to the impact of the mountain pine beetle in Western Canada [96].

[12] The directive on the promotion of the use of biofuels or other renewable fuels for transport set a 2% and 5.75% reference value for market shares of biofuels in 2005 and 2010 respectively.

Table 10
EU waste wood (*CN 44013080*) imports by region in ktonnes.

Country	2009	2010
Switzerland	414	471
Norway	339	430
Russia	138	168
Bosnia and Herzegovina	103	113
Croatia	105	95
Ukraine	66	103
Belarus	11	29
Liberia	0	37
Other	67	30
World	1243	1476

Data: [28].

Russian Federation

Despite several government statements and an abundant natural potential, Russia yet lacks a comprehensive national policy framework supporting RES – including solid biofuels. In recent years, partly due to the investment drop in the forestry and wood working sector, the national and also regional governments have however initiated smaller policy measures (primarily direct subsidies, partial compensations of payments on loans or interest rates) to stimulate the market [21,24,70,97]. There also appears to be a continuous increase in the use of small-sized wood-fired boilers in residential, municipal, and small industry heating applications, stimulating domestic demand for wood waste including sawdust pellets and briquettes [24,70].

Japan

The international commitment to cut GHG emissions has been an important policy driver for the development of bioenergy in Japan. In the past, energy utilities were incentivized to invest in solid biofuel combustion via financial incentives and regulatory measures such as the Renewables Portfolio Standard Law which covered biomass as of 2002 [21]. The market development was further stimulated by a general interest to make efficient use of forestry and wood processing industry residues (sustainable forestry has a long tradition in Japan due to its limited resources), the introduction of national standards (for pellets and equipment), the development of solid biofuel supply chains, and international cooperation [49,50]. Despite these policy efforts, Japan has however not yet become the long-time anticipated large-scale consumer for internationally traded bioenergy [40]. Current key markets are central and decentral residential and small business heating systems based on pellets, and increasingly also the co-firing of pellets in large power stations [38,49,50].

Table 11
Global wood pellet production 2000–2010 in ktonnes.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
USA	460	587	776	723	927	1062	1090	1180	1800	2800	3000
Canada	356	401	499	533	727	936	1145	1485	1335	1300	1320
Brazil							25	25	20	20	20
Argentina							7	7	7	9	10
Chile							20	60	20	20	20
Australia									5	5	125
New Zealand							20	20	50	100	110
South Africa										42	21
Japan	2	2	2	2	4	9	23	33	38	50	60
China									75	75	75
South Korea										20	170
EU27	840	1205	1360	1754	2278	3100	4696	6072	7507	8764	9286
Norway				20	34	42	51	45	35	68	193
Switzerland							35	70	74	112	112
Russia		2	4	8	30	50	350	550	550	840	800
Belarus							20	40	40	88	88
Ukraine							30	60	65	77	90
Bosnia H.									19	38	38
Croatia							21	41	41	77	77
Serbia									40	38	38
Total	1658	2197	2641	3040	3999	5199	7533	9687	11,721	14,542	15,652

Data: [11,21,23,28,38,41–54].

Table 12
EU wood pellet imports (*CN 44013020*) by region in ktonnes.

Country	2009	2010	Main type[a]	Main destination[b]
Canada	520	926	Industrial	NL, UK, BE
USA	535	736	Industrial	NL, UK, BE, DK
Russia	379	396	Industrial	DK, SE
Croatia	73	95	High quality	IT (partly via SI)
Belarus	75	90	Industrial	DK, DE, LI
Bosnia and Herzegovina	54	44	High quality	IT (partly via SI), SI
Ukraine	30	57	Industrial	PL, DK
Australia	9	63	Industrial	NL (partly re-export to EU)
South Africa	42	25	Industrial	UK, BE, NL
Serbia	18	26	High quality	IT, SI
New Zealand	0	21	High quality	NL, IT
Switzerland	6	15	High quality	IT, DE, AT
Other	31	27		
World	1771	2523		

Data: [28].
[a] Observations based on the predominant market in the importing countries.
[b] Trade route information based on interviews and [20].

Table 13
Intra-EU trade of wood pellets (*CN 44013020*) in ktonnes.

Country	2009		2010		Market share (2009–2010-average)		Traded types (majority)
	Imports	Exports	Imports	Exports	Imports	Exports	
Germany	230	351	339	532	8%	16%	Both types
Estonia	102	300	105	381	3%	12%	Industrial
Latvia	4	194	14	429	0%	11%	Industrial
Austria	206	159	227	284	6%	8%	High quality
Portugal	1	123	2	204	0%	6%	High quality
Finland	6	146	2	186	0%	6%	Industrial
Romania	0	60	1	139	0%	4%	High quality
Spain	218	60	48	138	4%	4%	High quality
Poland	32	81	11	136	1%	4%	Industrial
Denmark	891	20	1234	112	28%	2%	Both types
Lithuania	28	74	30	131	1%	4%	Industrial
Netherlands	173	67	98	126	4%	4%	Industrial
Sweden	422	98	496	68	12%	3%	Industrial
United Kingdom	128	6	374	67	7%	1%	Industrial
Belgium	232	119	145	46	5%	3%	Industrial
Italy	613	2	942	4	21%	0%	High quality
Other	682	306	1037	352			
EU	3355	2161	4165	3330			

Data: [28].

Table 14
Global charcoal data in ktonnes.

	Production			Import			Export		
	2007	2008	2009	2007	2008	2009	2007	2008	2009
Brazil	9194	8364	5058	304	42	85	13	5	6
Nigeria	3676	3762	3850	0	0	0	122	21	680
Ethiopia	3470	3556	3644	0	0	0	0	0	0
Germany	0	2	2	154	149	178	7	10	14
Korea, Republic of	12	8	32	127	113	116	0	0	0
Japan	30	28	26	141	146	151	1	1	0
Paraguay	684	684	684	0	0	0	408	426	208
Indonesia	681	681	681	0	0	0	210	201	199
Argentina	344	366	366	0	0	0	157	168	194
Malaysia	17	9	29	15	105	9	41	93	31
China	1749	1741	1733	75	136	157	43	52	55
Other	27,136	29,601	30,937	1051	1245	1323	597	579	730
World	46,993	48,802	47,042	1867	1936	2019	1598	1556	2119
						Data gap	*269*	*380*	*−99*

Production data: [26]; Trade data: [27].

Table 15
Global energy policy related net solid biofuel trade in PJ (own calculations based on [23,26–29,33,38–40,44,45,48,52,55,56,60–63,67]).

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Intra-EU trade excl. re-exports	3.4	3.6	3.6	5.1	8.1	12.8	13.9	30.0	36.3	57.0	71.8
Extra-EU imports	2.9	3.1	3.1	4.3	7.0	11.0	11.9	25.7	25.4	32.4	46.2
Canadian exports to US	2.2	2.8	4.2	3.8	4.8	4.8	8.3	9.1	8.1	5.4	0.7
Japan imports								0.3	0.8	1.1	1.5
South Korean imports									0.1	0.2	0.2
Net pellet trade	8.5	9.6	11.0	13.2	20.0	28.7	34.1	65.1	70.6	96.1	120.4
Intra-EU fuelwood trade	23.4	23.3	27.4	40.9	30.1	29.7	33.7	28.9	32.0	45.7	54.1
Extra-EU imports	3.4	3.1	3.7	6.0	9.9	10.9	16.3	14.8	15.3	25.2	21.7
Net fuelwood trade	26.8	26.3	31.0	46.8	40.0	40.6	50.0	43.7	47.3	70.9	75.8
Intra-EU wood chip trade	1.0	1.9	3.8	6.0	7.6	9.5	7.6	7.0	0.5	6.9	11.9
Extra-EU wood chip imports	0.4	0.9	1.7	2.7	3.4	4.3	3.4	3.2	0.2	3.1	5.4
Net wood chip trade	1.4	2.8	5.5	8.7	11.1	13.9	11.1	10.2	0.7	10.0	17.3
Intra-EU roundwood trade	0.2	0.4	0.7	1.1	1.4	1.8	1.4	1.3	0.1	1.3	2.3
Extra-EU roundwood imports	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.2
Net roundwood trade	0.2	0.4	0.8	1.2	1.6	2.0	1.6	1.3	0.1	1.3	2.4
Intra-EU wood waste trade	15.9	17.4	19.0	20.6	23.3	31.2	40.4	46.9	51.9	55.1	57.9
Extra-EU wood waste imports	3.3	3.3	3.4	3.4	4.1	5.9	8.2	10.9	13.4	16.2	19.2
Net wood waste trade	19.1	20.7	22.3	24.1	27.4	37.1	48.6	57.8	65.3	71.3	77.1
Extra-EU residue imports	0.7	1.4	2.9	4.5	5.8	7.2	5.8	5.3	0.0	4.1	7.2
Japan and South Korean imports									0.4	1.1	1.8
Net residue trade	0.7	1.4	2.9	4.5	5.8	7.2	5.8	5.3	0.4	5.2	9.0
Total (EU as one region)	12.9	14.7	19.0	24.8	35.1	44.2	53.9	68.9	62.7	87.5	102.2
Total global	56.5	60.9	72.7	97.3	104.2	127.5	149.4	182.0	184.2	253.5	299.6

South Korea

The first policy to apply to solid biofuels in South Korea was the 2nd Basic Plan for New and Renewable Energy Technology Development, Utilization and Deployment in 2003 under which biomass for heating and cooling received direct government support for investments and dissemination activities [98]. In 2008 South Korea launched its medium- to long-term National Energy Basic Plan for the period 2008–2030. As a result, the government has committed itself to actively support the development and deployment of non-fossil energy. In the past, the purchases of pellet boilers and the set-up of pellet plants received financial support from the national and local governments [48]. Pellets are mainly used in residential and mid-sized building heating systems [48]. In 2010, South Korea passed a Renewable Portfolio Standard which requires its power utilities to increase their share of RES to 2% of total power generation by 2012 and incrementally to 10% by 2022. Technically this could trigger large scale woody biomass demand for co-firing.

Appendix 2. Background data for Sections 3 and 4

Industrial roundwood

See Table 4.

Fuelwood

Wood chips

See Table 8

Waste wood

Wood pellets

Charcoal

Net solid biofuel trade

See Table 15.

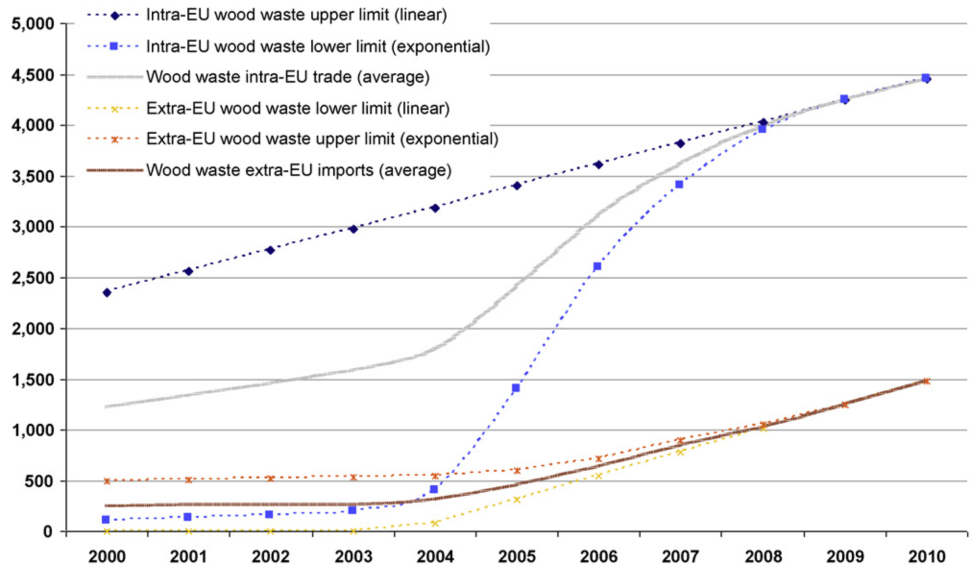

Fig. 12. Average extrapolation of EU trade volumes of wood waste in ktonnes. *Note*: The extrapolation builds upon data in [28] for 2009 and 2010. Both values are assumed maximums in their category (i.e. intra- and extra-EU trade). The upper limit for intra-EU trade is done via a linear extrapolation. The lower limit builds upon an exponential increase. Data for early years are taken from anecdotal evidence (i.e. assuming minimum trade to Sweden and Germany). Growing volumes are then attributed to the expansion of the EU and increasing interest in wood waste combustion across the EU MS. There is significant amount of uncertainty regarding the year of the inflection point (here in 2005). Total intra-EU trade is calculated as the average between the lower and upper limit. A similar procedure was taken for extra-EU trade (mainly imports from Norway and Switzerland). Here the lower limit was made as a linear extrapolation resulting in zero net trade prior to 2004. This is in-line with the growth timing of extra-EU trade (lower limit). The upper limit of extra-EU trade was calculated to have an exponential development. The total extra-EU trade was then taken as the average between the upper and lower limit.

Appendix 3. Conversion factors

	Applied in calculations			Ranges found in literature	
	Weight [tonne/m^3]	Heating value [GJ/tonne]	At moisture content	Moisture content	Bulk density [GJ/m^3]
Fuel wood/firewood logs[a]	0.275	18.75	20%	15–20%	5–9
Wood chips[a]	0.275	19.25	30%	15–50%	3–6
Wood residues[a]	0.3	19.25	57.5%	40–60%	3–5
Sawdust pellets[b]	0.7	18.30	9%	9–10%	10–13
Wood waste[c]	0.619	13.00	30%	20–50%	5–8
Palm kernel shells[c]	–	18.00	7%	6.5–8.4%	–
Charcoal[d]	–	22.00	4.5%	4.5%	–
Industrial roundwood[e]	0.8	18.40	30%	20–50%	7–15
Category *HS 440130*	0.3	19.25	50%		

[a] [10].
[b] [10,15].
[c] [99,100].
[d] [15,26,101]; 1 tonne of charcoal per 6 m^3 industrial roundwood.
[e] [15,102].
Others: [75].

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